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RAWSON

AND

BERGTHEIL.

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PREFACE.

THIS re-issue of Mr. Rawson's report and my own, bound together in book form and indexed, has been undertaken at the request of the Bihar Planters' Association in order that they may be available in a more permanent form, and in one more easy for reference, than has been the case hitherto. With the exception of one or two minor corrections in my own reports, they have all been reprinted exactly as they have already been issued. The pages are numbered as in the original reports, but, to facilitate reference, the abbreviated title has been printed on the edges of the pages of each report, which have been tinted in different colours. The index has been arranged to correspond with this by giving against each item a double reference, first to the particular report in question, and second to its page.

The present juncture is opportune for this re-issue since research work on indigo in India is now entering upon a new phase. Hitherto the larger part of the experiments carried out have been directed towards the improvement of the methods of manufacture, and a complete account of the work done in this direction will be found in this volume. The conclusion which has now been reached is that there is little room for further improvements in manufacture if the recommendations which have been made are adopted. Hereafter the work will, accordingly, be mainly devoted to efforts to increase the outturn of indigo from the unit area of land by means of improved plant, methods of manuring, and the like, and questions connected with manufacture will be looked upon as of secondary importance.

C. BERGTHEIL.

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December, 1909.

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REPORT

ON THE

CULTIVATION AND MANUFACTURE OF INDIGO.

(*For the Behar Indigo Planters' Association, Limited*).

BY

CHRISTOPHER RAWSON, F.I.C.

INTRODUCTION.

The investigation, the results of which are embodied in this report, was undertaken on behalf of the Behar Indigo Planters' Association and carried out during five successive seasons (1898–1902) in Behar. The first year (1898), the bulk of the work was done at Mozufferpore, the two following years (1899—1900) at Mohsheri Factory, an outwork of Doudpore, Tirhoot; and during the last two years at the head factory of Peeprah Concern, Chumparun.

During the period mentioned numerous short reports have been presented to the Association, but at the request of the Research Committee the more important results have been here collected and summarised. It has not been considered advisable to describe in detail the innumerable experiments which have been made as otherwise the report would be rendered far too voluminous for practical purposes.

Dr. Voelcker, in his excellent report on the "Improvement of Indian Agriculture," makes the following statement:—

> "It has been well said and cannot be too often repeated that
> "'India is a country about which one cannot make a *general*
> "remark,' and certainly with regard to Indian Agriculture this
> "is strictly true."

I have found this statement to be peculiarly applicable to work connected with the cultivation and manufacture of indigo. A certain manure may have given excellent results on some land but no advantage whatever on others of a similar class. Even on the same land duplicate and triplicate experiments are often contradictory, and the results of one season are not by any means always borne out by those of another. Again, in the manufacture of the dye great variations frequently occur without any apparent reason, and on this account experiments must be repeated a great number of times before any reliable conclusion can be drawn. Far too often planters have jumped to a conclusion that a process was either worthless or of great value from the results of one or two isolated tests conducted in anything but a scientific manner.

CULTIVATION OF INDIGO.

As all planters are aware, the land in Behar for the production of indigo varies very greatly in value. On some land the plant grows luxuriantly whilst on others it never appears to thrive well. It does not by any means necessarily follow, however, that the biggest crop is the best. The amount of potential colouring matter in plant varies so much that 50 maunds off some land will frequently yield more indigo than 100 maunds off others. Broadly speaking, tall plant, especially when the growth is unusually rapid, contains but a low percentage of colouring principle. Such plants not only contain a large proportion of woody fibre (stick) which is practically devoid of colouring matter but the leaves themselves contain a much smaller percentage of colouring matter than the leaves of smaller plant growing more slowly. When land is manured with the refuse plant ("seet"), growth is invariably much accelerated, but the big crop thus obtained gives, as a rule (for the reasons just stated), a comparatively poor return of indigo. The object of our experiments was of course to obtain an increased yield of *colouring matter* per acre or bigha of land. In a great many cases a more vigorous growth was obtained, but unfortunately as with "seet," though to a lesser degree, the plant was frequently found to be poorer in quality. Both at Mosheri and at Peeprah the best results were given by the application of a mixture of superphosphate of lime and saltpetre.

As no trustworthy analysis of indigo plant had been published prior to my taking up this research, I made several analyses in 1898 with a view of ascertaining what constituents were particularly required for the growth of the plant. These were detailed in my first annual report and the mean results (representing a typical analysis) need only be here reproduced. The analyses were made on the dried material but the results are calculated on the green plant as cut, on the basis of its containing (as it does on the average) 75 per cent. of water.

It has always been considered that the indigo plant grown in Bengal was *Indigofera Tinctoria*, but Major Prain, Superintendent of the Royal Botanic Gardens, Calcutta, in his annual report dated the 15th May, 1902, states that this is a mistake and points out that the plant is really *Indigofera Sumatrana* which was introduced into the province about 150 years ago.

TABLE I.—*Analysis of Indigo plant* (Indigofera Sumatrana) *showing leaves and stems separately.*

	AIR-DRIED.		GREEN PLANT.	
	Leaves.	Stems.	Leaves.	Stems.
Water	10·42	9·75	75·00	75·00
*Nitrogenous matters ..	29·37	5·94	8·19	1·65
Oil, etc., soluble in Ether ..	3·85	1·05	1·07	·29
Woody fibre	11·07	47 50	3·09	13·16
Carbo-hydrates and other organic matter ..	33·29	31·01	9·30	8·60
†Mineral matter (ash) ..	12·00	4·75	3·35	1 30
	100·00	100 00	100 00	100·00
Matter soluble in water—				
Organic	25·05	9·05	6·99	2·51
Mineral	7·55	2·65	2·11	·73
*Containing Nitrogen ..	4·64	·94	1·293	·260
†Mineral matter containing—				
Silica	·628	·051	·175	·013
Phosporic Acid ..	·916	·344	·255	·095
Sulphuric Acid ..	·296	·074	·084	·021
Carbonic Acid, etc. ..	2·885	1·163	·806	·323
Chlorine	·050	·074	·014	·021
Oxide of Iron and Alumina	·086	·020	·024	·006
Manganese Oxide ..	·040	·025	·011	·008
Lime	3·591	1·275	1·002	·353
Magnesia	1·298	·164	·362	·045
Potash	2·210	1·460	·616	·404

As in practice the whole plant is dealt with, it will be well to show the average analysis of the whole plant as put into the steeping-vats. This is not such an easy matter as it might appear on account of the enormous variation in the proportion of leaf and stem to be found in different samples. I have known plant put into the steeping-vats containing no more than 10 per cent. of leaf, whilst occasionally, though not often, the proportion of leaf rises to as much as 60 per cent. In round numbers, good plant may be taken to consist of 40 parts of leaf and 60 parts of stem. On this basis, the composition of the whole plant will be as follows :—

TABLE II.—*Showing Composition of whole Green Plant.*

Water	75·00
Nitrogenous matters	4·27
Oil, etc., soluble in Ether	0·60
Woody fibre	9·14
Carbohydrates and other organic matter ..	8·87
Mineral matter (ash)	2·12
	100·0

Matter soluble in water :—	
Organic	4·300
Mineral	1·280
Containing Nitrogen	0·673

Mineral matter containing—	
Silica	0·078
Phosphoric Acid	0·159
Sulphuric Acid	0·040
Carbonic Acid, etc.	0·519
Chlorine	0·018
Oxide of Iron and Alumina	0·013
Manganese Oxide	0·009
Lime	0·615
Magnesia	0·172
Potash	0·491

In order to show more clearly the mineral matter taken up by the plant it will be best to represent the composition of the ash in 100 parts as follows :—

TABLE III.—*Composition of Ash of Indigo Plant.*

	Leaves.	Stems.
Silica	5·23	1·10
Phosphoric Acid	7·64	7·40
Sulphuric Acid	2.46	1·58
Carbonic Acid, etc.	24·05	25·03
Chlorine	0·41	1·58
Oxide of Iron and Alumina ..	0·71	0·43
Manganese Oxide	0·33	0·53
Lime	29·94	27·43
Magnesia	10·82	3·50
Potash	18·41	31·42
	100·00	100·00

It will thus be seen that the indigo-yielding plant (especially the leaf) is rich in nitrogen and also contains a comparatively large amount of mineral matter. There is nothing remarkable about the composition of the mineral matter although it may be noted that the ash of the leaf contains rather a high percentage of magnesia. A little calculation will show that a crop of indigo carries away a considerable amount of plant food from the soil. In order to arrive approximately at this amount it is necessary to know what is the weight of plant yielded by an acre of land and, as is well known, this is a very variable quantity. A fair average crop may be taken at 50 to 80 cwts. (75 to 120 maunds) per acre. On the basis of the lower number, a crop removes 118 lbs. of mineral matter from an acre of land. Of this amount 9 lbs. are phosphoric acid, 27⅓ lbs. potash, and 10 lbs. magnesia. The crop from an acre of land also contains 38 lbs. of nitrogen, but indigo being a leguminous plant, the bulk of this nitrogen is most probably derived from the atmosphere and not from the soil.

Soils.—In my first annual report alluded to above, the composition of several soils was given. Numerous analyses have been made since, but with one or two exceptions they call for no special comment. The following analyses may be cited as representing typical soils of the district

TABLE IV.—*Composition of Soils.*

In 100 parts of dry soil.	Chumparun soils.		Dooriah (Tirhoot) October 5th 1899.		Sathi (Champarun) October 6th 1899. Stiff clay soil.		Mosheri (Tirhoot) October 19th 1899.		Mosheri "Beet" drain.	Peeprah Experimental plots, 1901.		Peeprah Experimental plots, 1902.	Kurnoul old saltpetre soil, July, 1899.	Peeprah Bhusa House soil.	
	Light Sandy. (1)	Heavy Clay. (2)	Surface. (3)	Sub. soil. (4)	Surface. (5)	Sub-soil. (6)	Surface. (7)	Sub-soil. (8)	Surface. (9)	Surface. (10)	Sub-soil. (11)	Surface. (12)	(13)	Rich. (14)	Barren. (15)
*Organic matter and combined water ...	1·40	1·95	1·66	·95	2·71	2·70	1·36	1·29	5·62	3·28	1·71	3·31	2·61	7·63	7·65
Sand and insoluble silicates	53·85	87·55	51·00	46·60	85·17	87·00	56·85	52·25	56·88	53·20	51·80	55·83	49·96	52·10	50·08
Phosphoric Acid	·17	·13	·21	·16	·08	·07	·14	·10	·42	·19	·22	·28	·33	·32	·34
Carbonic Acid, etc. (by diff.) ...	17·37	1·06	19·43	21·42	1·83	·29	16·97	17·71	13·27	17·29	19·22	14·53	18·98	14·81	14·28
Oxide of Iron	2·25	3·90	1·96	2·20	3·77	3·32	2·20	2·70	4·00	2·08	2·25	2·58	2·19	3·23	3·39
Alumina	3·75	4·20	1·23	3·00	4·70	5·41	2·03	3·2	1·97	2·02	2·20	3·12	3·76	3·26	2·55
Lime	20·60	·42	22·23	24·95	·62	·42	19·61	21·61	15·68	20·93	21·44	18·50	21·33	18·03	17·81
Magnesia	·22	·45	1·88	·47	·78	·46	·58	·84	1·53	·66	·82	1·35	·43	1·74	1·89
Potash	·34	·30	·40	·35	·34	·33	·26	·30	·57	·35	·34	·50	·41	·71	1·07
														·17	·94(Soda)
	100.05	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100.00	100·00	100·0
*Containing Nitrogen	·065	·055	·057	·029	·056	·038	·052	·024	·330	·280	·230	·280	·056	...	...
Equal to Ammonia	·078	·066	·070	·036	·068	·046	·063	·029	·400	·340	·280	·340	·068	...	...
Available Phosphoric Acid	...	...	·013	·016	·021	·021	·010	·008	...	...	...	·009	·028	...	...
Available potash	...	...	·042	·035	·036	·032	·025	·033	...	...	...	·026	·023	...	..
Soluble salts	...	...	...	...	...	...	...	...	...	...	...	·60	...	1·05	3·71

It might be well to explain the terms "available phosphoric acid" and "available potash" which have not appeared in my former reports. The total amount of phosphoric acid in a soil acts as a guide as to whether the application of phosphates is likely to be beneficial or not, but much depends upon the state in which it exists. A soil may show on analysis a comparatively large proportion of phosphoric acid and yet little of it may be in a condition assimilable by the plant, and *vice versa*. Dr. Bernard Dyer found that a close relationship existed between the fertility of a soil and the amount of phosphoric acid which was dissolved under certain conditions by a 1% solution of citric acid, and on this property founded a process for determining the amount of so-called "available phosphoric acid" which has been generally adopted by agricultural chemists. Likewise as regards available potash. Dr. Dyer's process was followed in the cases given, but, unfortunately, time and opportunity did not permit of its being systematically used for various classes of soils of known fertility.

Samples 7, 8, 10, 11, and 12 represent soils upon which manurial experiments were carried out and will be referred to later.

Sample 9 is inserted in the table in order to show the composition of a rich soil. It had been enriched by the drainage water from a "seet" heap, and upon it a crop of mustard grew most luxuriantly, whereas on the adjoining land (similar in composition to soil No. 7) the growth of the same crop was poor and much below the average. It will be observed that this soil (No. 9) contained a high percentage of each of the three principal constituents of plant food, *viz.*, phosphoric acid, nitrogen and potash. It is also noteworthy that the proportion of magnesia was much enhanced by the drainage water, and, as might be expected, the soil contained a high percentage of organic matter.

Sample No. 13 is described as an "old saltpetre" soil, and one would therefore expect it to contain a high percentage of nitrogen, but on the contrary it proved, on analysis, to contain a very small amount of that element. Indigo plant grew upon this soil exceedingly well, and the "colour" obtained from it was of high quality. The chief feature about the soil, as revealed by analysis, was its high percentage of "available" as well as *total* phosphoric acid.

Samples 14 and 15 are inserted in the table in order to show the effect of an excess of soluble salts in a soil. The samples were taken at Peeprah at and near a spot upon which an old "Bhusa" house

had previously stood. The land had been ploughed and prepared in the usual way and sown with indigo. Where the house had actually stood (represented by sample 15) scarcely any seed germinated and the land appeared quite barren, but just on the borders, from which sample 14 was taken, the plant germinated and grew luxuriantly. Both samples contained a large amount of organic matter and of phosphoric acid; the chief difference was in the amount of saline matter soluble in water, consisting principally of salts of potash and soda. The abnormal amount of soluble potash and soda salts in sample 15 was evidently the cause of indigo seed not germinating in the soil.

It is no doubt on this account that land which has been too heavily "seeted" frequently yields but a poor return the first year in comparison with subsequent years. This is likely to be all the more pronounced when the "seet" is taken direct from the steeping-vats as it then contains a large amount of soluble matter which otherwise (when the refuse plant is left in a heap) partially drains away.

Referring again to my first annual report with regard to the general characteristics of indigo soils, I stated that all the samples examined contained an abundant supply of potash, and also that although the amount of phosphoric acid varied considerably, it was on the whole present in sufficient quantities. Regarding the latter statement, a more extended experience has led me to modify that view as many soils (not by any means all, however) are deficient in phosphoric acid. This was particularly shown by the determination of the "available" phosphoric acid in various samples and further confirmed by manurial experiments, especially by those carried out at Mosheri.

Refuse Plant or "Seet."—It is well known that waste plant taken from the steeping-vat is a valuable manure, but hitherto little, if anything, has been published regarding its composition or real manur al value. In Table II the composition of average green indigo plant is given. On steeping, numerous constituents in addition to the colouring principle (chiefly from the leaves) are dissolved, and the composition of the residue is thereby changed. Average plant contains rather more than 5 per cent. of dry matter soluble in water, and from two-thirds to three-fourths of this amount is removed during steeping. As only a small proportion of the nitrogenous substances dissolve, the refuse plant is richer in nitrogen than the original. It likewise contains a higher percentage of phosphoric acid.

Table V shows the general composition of a representative "seet" from Mosheri Factory. Three large samples were taken from the heap in February 1901, one from near the top, one at a depth of about 5 feet, and the third at a depth of 12 feet near the bottom. The samples were analysed separately but the figures given are the mean results of the three. The sample taken from near the top was found to be rather richer than the others, probably owing to the fact of its being drier and containing rather more leaf. The second and third samples were very nearly of the same composition—almost identical in fact, as regards the more important constituents.

TABLE V.—*Composition of "Seet" after standing in heap behind the steeping-vats from* 1900 *Mahai until February* 1901

Water	72·56
*Organic matter	22·88
†Mineral matter	4·56
	100·00
*Containing nitrogen	·98
Equal to ammonia	1·19
†Containing—	
Silica	1·04
Lime	1·09
Magnesia	·21
Potash	·89
Phosphoric Acid	·27
Phosphoric Acid equal to Tribasic Phosphate of Lime	·58

As already mentioned, "seet" is a very valuable nitrogenous manure, but from numerous observations and experiments it appears to be much more suitable for other crops (sugar, tobacco, cereals, oil-seeds, opium, etc.) than for indigo. I should certainly not recommend indigo to be grown on newly-seeted land.

In its general composition "seet" closely approximates to English Farm-yard Manure though it is decidedly richer in its chief constituent, nitrogen. For comparison, I give below in Table VI, analyses of English Farm-yard Manure and of Indian Cattle Manure taken from Dr. Voelcker's Report on Indian Agriculture.

TABLE VI.—*Composition of Farm-yard Manure and Indian Cattle Dung.*

	English Farm-yard Manure.	Dung from grain-fed Cart-bullocks (air dried).
Water	66·17	17·86
*Organic matter	28·24	61·89
†Mineral matter	5·59	20·25
	100·00	100·00
*Containing Nitrogen	·65	1·08
Equal to Ammonia	·79	1·31
†Containing—		
Silica	1·76	16·75
Lime	1·35	·85
Magnesia	·15	·30
Potash	·67	·60
Phosphoric Acid	·31	·54
Phosphoric Acid equal to Tribasic Phosphate of Lime	·68	1·18

It will be thus seen that English Farm-yard Manure contains only two-thirds as much nitrogen as "seet." Bullock-dung, as shown in the above analysis, contains slightly more than "seet," but it should be pointed out that the sample was "air-dried," and if calculated with the same amount of water the nitrogen would be very much less than in "seet."

Without taking into consideration the organic matter (the value of which cannot well be calculated), one ton of "seet" is equivalent as regards its three principal plant food constituents to 103 lbs. sulphate ammonia, 36 lbs. sulphate of potash and 13 lbs. tribasic phosphate of lime. If, therefore, we place the same value on the nitrogen, potash and phosphoric acid in "seet" as in sulphate of ammonia, sulphate of potash and phosphate of lime respectively, and take the current ruling prices of these manures *in Behar*, then the value of a ton of "seet" works out to 18 shillings (Rs. 13-8).

The nitrogen in one ton of "seet" is equivalent to 158 lbs. of pure

saltpetre which, at Rs. 180 per ton, works out to about the same value.

It must be borne in mind that the nitrogen in "seet" exists in quite a different state of combination to that in sulphate of ammonia or in nitrate of potash (saltpetre), and the value thus assigned by calculation from analysis must be viewed more or less as a theoretical value. However, it is one generally adopted, and is, broadly speaking, borne out by practical results.

It might be interesting to compare "seet" with oil-cake manure which much more closely approaches it in general composition than do the mineral fertilisers. Castor-cake contains from 4 to 5 per cent. of nitrogen, 1½ per cent. of phosphoric acid and about 1 per cent. of potash. One ton of "seet" such as that represented by the analysis in Table V is equivalent in manurial value to about 5 cwts. of castor cake which, at Rs. 50 per ton, works out to Rs. 12-8 (16-8).

Oil-cake is a dry product containing but 14 per cent. of moisture, and if the "seet" were dried to the same extent it would contain nearly as much nitrogen and phosphoric acid as castor-cake and considerably more potash.

"Seet," like oil-cake, contains a large amount of organic or vegetable matter which, irrespective of any chemical properties, undoubtedly acts beneficially in a physical sense on the soil in retaining moisture, etc. The soils of Behar are generally deficient in vegetable matter.

It must be understood that the above remarks about "seet" refer to the material which has been left in a heap for some months. In some factories the practice obtains of carting the refuse plant direct from the steeping-vats on to the land. In this state the "seet" is heavily charged with water and is therefore not nearly so rich as that represented in Table V. One ton of refuse plant taken direct from the vats is equal to only about 12 cwts. of the "seet" under discussion.

It might be well to briefly discuss here the value of "seet" as a manure in comparison with that of the indigo obtained from the original plant. In round numbers, 100 maunds of green plant may be taken to give on an average 10 seers of indigo which, at Rs. 160 per maund, would be worth Rs. 40.

From 100 maunds of green plant about 80 maunds of good "seet" would be obtained, which at Rs. 12-8 per ton, would be worth Rs. 37 or nearly as much as the indigo. There are many

factories where the average outturn never approaches 10 seers per 100 maunds, and it may well happen that the value of the "seet" as a manure considerably exceeds that of the indigo obtained from a given weight of plant.

The high value of "seet" as a manure has an important bearing on the position of the indigo industry. Whatever may be price of indigo as a dye, it should, in my opinion, pay to continue to cultivate the plant in conjunction with other crops, providing the "seet" is judiciously applied. The soils of Behar and, in fact, of India, generally, are deficient in nitrogen, and in order to grow such crops as sugar, tobacco, cereals, etc., successfully, nitrogenous manures must be employed; and for these purposes "seet" is eminently suitable. To apply seet, however, *direct* to land for indigo is, in my opinion, distinctly irrational and wasteful.

Experiments with Manures.—1. The first series of experiments were made in 1900 at Mosheri on soil represented by analyses 7 and 8 in Table IV. Fourteen plots ($\frac{1}{4}$ acre each) in quadruplicate were laid out in order to try the effect of various manures on the growth of indigo. The young plant was to a great extent destroyed by caterpillars and the crop was not by any means a good one. Nevertheless, some striking differences were to be observed among the various plots. When ready for "mahai," the plant was cut and put into cages ready for steeping, and the part cut, measured. Two tests were made from each plot, making eight separate tests for each kind of manure. The plant (3 maunds for each test) was worked off in a series of six experimental vats built for the purpose. The manures and the results obtained are given in the following table :—

TABLE VII.—*Results of Experiments with Manures at Mosheri*, 1900.

No. of plot.	Manures per acre.	Maunds (imperial) of plant per acre.	Seers 60 per cent. indigo per 100 maunds.	Seers 60 per cent. indigo per acre.
1	Castor-cake, 800 lbs. ..	80·5	10·62	8·65
2	Seet, 2½ tons	90·5	9·85	8·91
3	Seet, 5 tons	111·3	7·86	8·75
4	Bone-meal, 160 lbs.	63·0	13·51	8·50
5	Saltpetre 160 lbs.	57·8	13·96	8·10
6	Sodium Nitrate, 160 lbs. ...	60·2	13·78	8·30
7	Bone Superphosphate, 160 lbs. ..	76·1	14·00	10·66
8	Saltpetre, 320 lbs.	63·2	13·77	8·70
9	Bone-meal, 160 lbs., saltpetre, 160 lbs.	62·8	14·42	9·05
10	Bone Superphosphate, 160 lbs, saltpetre, 160 lbs.	86·3	12·74	11·00
11	Calcium Sulphate, 502 lbs., saltpetre, 160 lbs.	59·3	13·48	8·00
12	Magnesium Sulphate, 500 lbs., saltpetre, 160 lbs. ..	63·1	14·60	9·20
13	Iron Sulphate, 48 lbs., saltpetre, 160 lbs.	56·8	14·00	7·96
14	Unmanured	59·3	13·75	8·16

It will be observed that "seet," especially the larger quantity, gave much the greatest weight of plant per acre, but it was of inferior quality and the amount of indigo obtained per acre was little more than that yielded by plant grown without manure. Superphosphate, in conjunction with saltpetre, gave the best results though the mixture was closely followed by superphosphate alone.

Compared with the unmanured plot, superphosphate a one, at an approximate cost of Rs. 5, gave an increased yield of 2½ seers of indigo worth (at Rs. 160 per maund) Rs. 10.

The extra amount of indigo obtained in this particular experiment by the addition of saltpetre would not repay the cost of the saltpetre though probably a smaller quantity might prove remunerative.

Castor-cake gave a considerable increase of plant, but like that grown with "seet" it was of inferior quality.

Bone-meal produced very little effect though it should be stated that the material used was not as finely powdered as it should have been.

Saltpetre alone, and in conjunction with bone-meal, calcium sulphate and iron sulphate respectively, produced no increase, but a mixture of saltpetre and magnesium sulphate gave an increase of 1 seer of indigo per acre. Unless this increase could be obtained by the use of smaller quantities, however, it is of little practical importance.

II.—The second series of experiments were made at Peeprah in 1901 on soil represented by analyses 10 and 11 in Table IV.

Twelve plots of 1/8 acre each, in triplicate, were marked out and treated with various manures. The young crop again suffered from an attack of caterpillars, and, moreover, the plants which escaped and those from re-sowings grew somewhat in patches. From the wavy growth of the crop across the line of plots it became evident that the land was not of an even character although four samples of soil taken from different parts of the field showed on analysis very little variation.

The plant was cut in August and treated in small steeping-vats as in the former case mentioned above. In one set of plots the crop was too irregular to be of any value, so the results tabulated below represented the mean figures obtained from two sets of experiments only.

The figures of Table VIII (p. 15) are given for what they are worth, though I am afraid, on account of the irregularity of the land, they are not of great value. It is true that taking the mean results, superphosphates gave a considerable increase though, if plots C only were taken into account, the increase would be nil. There is little to be gained by discussing the above experiments in detail, but the general conclusion may be drawn that on such land the application of fertilisers for indigo does not repay their cost. On reference to Table IV it will be observed that the soil (Nos. 10 and 11) contains more than an average amount of phosphoric acid and also a comparatively high percentage of nitrogen. The land was chosen as a suitable plot for experiments on account of its not having been "seeted" for some years. It proved, however, to be richer than had been anticipated, but when the selection had to be made there was no time to make analyses of it and other soils in the neighbourhood. Regarding this series of experiments it should also be noted that heavy rain occurred more than once during the cutting of the plant and steeping of the same, and thus interfered with the accuracy of the results.

TABLE VIII.—*Results of Experiments with Manures at Peeprah*, 1901.

No. of plot.	Manures per acre.	Maunds (imperial) of plant per acre. B.	C.	Mean.	Seers 60 per cent. indigo per 100 mds.	Seers 60 per cent. indigo per acre (mean).
1	Unmanured ..	70·0	102·7	86·3	11·30	9·75
2	Castor-cake, 2 cwts. ..	80·7	104	93·3	10·43	9·62
3	Castor-cake, 4 cwts. ..	107	131	119	9·50	11·30
4	Bone-ash, 3 cwts. ..	104·7	109	106·8	10·23	10·92
5	Bone-ash, 3 cwts., saltpetre, 84 lbs. ..	106·4	108	167·2	9 94	10·65
6	Mineral Superphosphate, 4 cwts.	154	128	141	8·20	11·56
7	Mineral Superphosphate, 4 cwts., saltpetre, 84lbs.	151	106·4	128·7	9·20	11·84
8	Bone Superphosphate, 5 cwts.	152	101·5	126·8	8·94	11·30
9	Bone Superphosphate 5 cwts., saltpetre 84 lbs.	165	98·7	131·8	8·87	11·69
10	Iron Sulphate, 56 lbs. ..	144·6	99·7	122·1	9·40	11·48
11	Iron Sulphate, 56 lbs., saltpetre, 168 lbs. ..	150	100	125	8·85	11·06
12	Mineral Superphos., 4 cwts., saltpetre, 84 lbs., Iron Sulphate, 56 lbs.	123	102	112·5	9·50	10·68

III.—The third series of experiments were carried out on land nearer the laboratories at Peeprah during the season 1902. Seven samples of soil taken from different parts of the field were analysed and the average results are detailed under No. 12 in Table IV. The different samples showed very little variation, but here again the land proved to be richer in phosphoric acid and nitrogen than one would have wished for experimental purposes.

Eleven plots (of 1/28 acre each) in quadruplicate were measured and treated with various manures as shown in Table IX. The plant grew well on all the plots and showed very little variation. It was left standing until the last week in August when the crop from each plot was weighed and the colouring matter determined by means of the "kier" apparatus.

TABLE IX.—*Results of Experiments with Manures at Peeprah*, 1902.

No. of plot.	Manure per acre.	Maunds (imperial) of plant per acre.	Seers 60 per cent. indigo per 100 maunds.	Seers 60 per cent. indigo per acre.
1	Unmanured	198	5·10	10·10
2	Bone-ash, 4 cwts.	183	6·00	10·98
3	Bone-ash, 4 cwts., saltpetre, 168 lbs.	185	6·14	11·40
4	Mineral Superphosphate, 4 cwts. ..	195	5·70	11·11
5	Mineral Superphosphate, 4 cwts., saltpetre, 168 lbs.	188	6·74	12·68
6	The same as No. 5 with addition of Magnesium Sulphate, 2 cwts.	183	5·60	10·24
7	The same as No. 5 with addition of Iron Sulphate, 56 lbs ..	190	6·20	11·78
8	Mineral Superphosphate, 4 cwts., Iron Sulphate, 56 lbs. ..	176	6·60	11-61
9	The same as No 5 with addition of Manganese Sulphate, 56 lbs. ..	186	5·80	10·78
10	Mineral Superphosphate, 4 cwts., Ammonium Oxalate, 1 cwt. ..	195	5·34	10 41
11	Mineral Superphosphate, 4 cwts., Ammonium Sulphate, 1 cwt. ..	187	5·94	11·11

It will be observed that the plant gave but a small return of indigo per 100 maunds, but the weight of plant per acre was above the average. It should have been cut at an earlier date but other urgent work prevented this being done.

The unmanured plots actually produced a greater weight of plant than the manured, but the plant contained less colouring matter. Superphosphate alone, and in various combinations, gave a decided increase of colouring matter, but not to such an extent as to repay the cost of the fertilisers. In all probability, however, the manures would be found to have an effect on the crop the following season, but the experiments were not continued. From the results of one season only it would again appear that it does not repay to manure such land for the cultivation of indigo.

In connection with these three series of manurial experiments I may add that in 1901 trials were made at Peeprah with superphosphate alone and with superphosphate in conjunction with saltpetre on

the large scale. The trials were made in two sets, some little distance apart; in one case 7-acre plots and in the other 13-acre plots.

1.. Unmanured.
2. Mineral superphosphate, 3 cwts. per acre.
3. The same as No. 2 with addition of saltpetre, 84 lbs. per acre.

The manures were applied as a top dressing in May. The results obtained were not satisfactory and the two sets did not agree with each other.

TABLE X.—*Maunds of plant obtained per acre in Peeprah Trials on large scale*, 1901.

—	7-acre set.	13-acre set.	Taking the whole 20 acres as one trial.
1	111·4	139·3	129·5
2	80·7	144·7	122·3
3	72·0	14·6	120·1

Before being cut, both lots of manured plant in the 13-acre set looked considerably higher and better than the unmanured, and a greater difference in weight than that obtained was certainly expected. The crop on the 7-acre plots was not at all regular and the difference in weight was no doubt accidental. It is highy improbable that the application of superphosphate could in any way retard the growth of a crop.

Vat trials were not made with the bulk, but samples of plant from each plot were analysed in the laboratory. In the 7-acre set all the samples were found to contain practically the same amount of colouring matter, but, strange to say, in the 13-acre set, plant from the unmanured plot yielded more colouring matter than that from either of the maaured plots.

The soil upon which these experiments were carried out was not analysed, but from its proximity to the small experimental plots and from general observations it most likely had a composition similar to 10 and 11 detailed in Table IV, and hence was not deficient in phosphoric acid and nitrogen. It is evident that the land received no immediate benefit from manuring.

Time of year when manures should be applied.—Before leaving this subject of manuring there is one important point which should not be overlooked. In all the above experiments the artificial manures were either applied just before sowing or as top dressings, and in some cases, from unavoidable causes, the application was delayed until late in the season.

In the first series of experiments (at Mosheri) the manures were applied in February; in the second (Peeprah 1901) in March; and in the third series (Peeprah 1902) in April. In the Peeprah large scale trials (1901) the manures were not applied until the middle of May, and as the crop was cut before the end of July there was little time for the fertilisers to take effect.

With regard to the small experimental plots the time of year chosen (although with the exception of one set it could not have been arranged otherwise) was for many reasons considered to be the best, but I have since come to the conclusion that this was a mistake and that manures to be really effective should be applied at a much earlier date. Had this been done, probably very different results would have been obtained. Superphosphates gave the best results at Mosheri when applied early in February. I quite agree with Mr. B. Coventry that manures should be applied not later than September in the previous year for the reasons given on pp. 2 and 5 of his Indigo Report (dated 24th January 1902) to the Indigo Improvements Syndicate. This opinion applies more particularly to general indigo cultivation and to trials on the large scale. With small experimental plots a very heavy shower of rain might cause some confusion although "soluble" manures are not washed out of the soil so readily as was imagined. An objection might be raised to this early application of manures on the ground of the possibility of the seed not germinating from lack of moisture or from other causes. But in such an event the manure would not be lost as it would be useful for some other crop or for indigo the following year.

Dalsingsarai Experiments.—I have already called attention to one or two anomalies which occurred in my own experiments with manures and perhaps may be permitted to do the same with regard to the experiments conducted at Dalsingsarai.

In the report above mentioned, Mr. Coventry refers specially to plot No. 17 in set B which in 1900 gave an increase (compared with unmanured) of 24 lbs. of 60 per cent. indigo per acre, and in 1901 an increase of 13 lbs. Now plot No. 46 in the same series had

precisely the same phosphoric acid and nitrogen but more potash than No. 17, yet it produced in 1900, 9 lbs. less indigo than unmanured, and in 1901 there was only an increase of 5 lbs. per acre. No. 16 plot in the same set also had the same amount of phosphoric acid and nitrogen as No. 17 but rather *less* potash (60 lbs. instead of 80 lbs.), and this plot yielded each year practically the same amount of indigo as the unmanured portion. The table contains other anomalies of a similar character. The cost of manures per acre on plot No. 17 was Rs. 57, which is the value of 14¼ seers (26·6 lbs.) of indigo at Rs. 160 per maund.

I mention these points, not with a view of making it appear that fertilisers have no practical value for indigo, but, to show that much more work is still needed before one can be justified in drawing general conclusions as to the kind and quantity of manures to be applied in order to obtain remunerative returns.

I am of opinion that little more can be said on the subject at present than that superphosphates can be applied to certain indigo soils with advantage whilst they have little or no effect on others. Also, that nitrogen in the form of nitrates, in conjunction with superphosphates, usually increases the production, but on account of cost it is questionable whether the use of nitrates will generally prove remunerative.

Colouring matter in plant.—In connection with the cultivation of indigo the amount of colouring matter obtainable from leaves of various kinds of plant, at different periods of the year and under various conditions, may be conveniently discussed. It has already been stated that the colouring principle from which indigotin is derived exists almost exclusively in the leaf of the plant, and since the proportion of leaf is a very variable quantity, the experiments to be now described were confined to leaves only. In many cases the proportion of leaf was also ascertained in order to determine the amount of colouring matter obtained or obtainable from the whole green plant. In the earlier analyses the amount of indigotin yielded by leaves was estimated by steeping experiments, but this method, in addition to occupying much time, had several drawbacks, and an investigation with the object of improving the process was undertaken. It was found that the colouring principle could be extracted by boiling water in a few minutes, and contrary to expectations it remained unchanged for a considerable length of time. The solution obtained in this way differs greatly from that yielded by steeping

or by water at a temperature of about 150° F., inasmuch as no fermentation takes place and the colouring principle exists as it does in the leaf, *viz.*, in the form of a glucoside. Beating or blowing direct with air or oxygen does not produce indigotin. In order to split up the glucoside and convert one of the products into indigo, it is necessary either to submit the solution to the action of enzymes followed by air or to treat it with certain oxidising agents in the presence of an acid. Various oxidising agents, such as ferric chloride, potassium chlorate and peroxide of hydrogen were tried, and after numerous experiments, persulphuric acid was found to give much the best results. The following is an outline of the process finally adopted for determining the amount of colouring matter in the leaf or the plant :—

Twenty grammes of leaves are introduced into 250 cc. of boiling water and the boiling continued for two minutes.

The solution is strained off through muslin, the mass of leaves squeezed and well washed with boiling water. The solution is treated with 5 cc. of hydrochloric acid (containing 20% HCl) and 40 cc. of a 5% solution of ammonium persulphate. The persulphate is not added all at once; at first 2 cc. only are added and after half-an-hour 2 cc. more, and again 2 cc. after another half-an-hour. After two hours from the commencement of the operation, the remainder of the ammonium persulphate is added, and, on standing for a further period of an hour, the solution is heated and filtered through asbestos. The indigotin thus obtained is washed, dried and further treated as in the ordinary analysis of indigo.

Colouring matter in leaf at different periods of the season.— The following figures show the percentage of indigotin found in leaf of the ordinary plant (*Indigofera Sumatrana*) at different periods of the year. The successive samples in each series were taken from or near the same spot :—

		Percentage of indigotin.
Mosheri, 1901	April 28th	·38
	May 15th	·52
	May 28th	·58
Peeprah, 1901	May 28th	·30
	June 15th	·45
	July 30th	·53
	Aug. 25th	·76
	Nov. 10th	·25

		Percentage of indigotin.
Peeprah, 1902	April 25th	·35
	May 5th	·40
	May 29th	·45
	June 23rd	·47
	July 27th	·51

From these experiments it is clear that as the season advances the amount of colouring matter gradually increases, but with the advent of cold weather (according to the test at Peeprah in 1901) it rapidly falls. The leaf, as a rule, contains a maximum amount of colouring matter from about the middle to the end of August, but it does not necessarily follow that this is the best period for manufacture as by this time the plant will usually have lost a considerable proportion of leaf. If it can be possibly avoided, however, it is a mistake to commence "mahai" very early. It is best to have plenty of vat-room so as to be able to work off the crop as quickly as possible, say from about the middle of July.

New and old leaf.—Although the leaf on *young* plant contains but a small percentage of colouring matter, yet as the plant grows the new leaf is found to contain more colouring matter than the old on the same plant. On three different occasions in June 1901, the following results were obtained :—

Percentage of Indigotin.	
New leaf.	Old leaf.
·71	·35
·62	·40
·71	·40

There is a gradual increase in the percentage of colouring matter in leaves from the bottom of the plant upwards, as shown in the following two sets of experiments :—

	Percentage of Indigotin.	
	A.	B.
Leaf from bottom of plant ..	·25	·30
Leaf from middle of plant ..	·30	·44
Leaf from top of plant	·55	·62

Leaf at different hours of the day.—Samples of leaf were taken hourly from the same plants, from 7 A.M. to 5 P.M., and tested for colouring matter. The variation in the amount found was very slight, not greater than that which could be reasonably attributed to experimental error.

Effect of rain on the colouring matter.—On many occasions leaf was examined for colouring matter after heavy rain, and experiments were also made by pouring water continuously for some time on to plant. Notwithstanding the fact that after heavy rain "produce" invariably falls, the results conclusively proved that rain does not wash out any of the colouring principle from the leaf. The fall in "produce" on such occasions is due to a variety of causes. In the first place the plant is weighed wet, and it is not usual to make any allowance in factories for this added water which may amount to as much as 25 to 30 per cent. Again, after heavy rain the "mal" does not settle well and much indigo is often run away in the "seet" water. After making these allowances, however, there is frequently a diminution of "produce" to be accounted for; this is most probably due to imperfect fermentation through a lowering of the temperature, and possibly to the washing away of *enzymes* from the plant.

Much of the loss which occurs under such conditions could be avoided by raising the temperature of the water and giving a little extra steeping.

Burnt plant.—If green indigo plant is kept in a heap for some time, fermentation sets in, accompanied by a great rise in temperature, and the leaves turn black. This change takes place more rapidly on hot sultry days when the humidity of the air is high. On such occasions, carts coming from a long distance are frequently found on arrival at the factory to contain more or less plant which has turned black and which is said to be "burnt." Plant in this condition is practically devoid of colouring matter and should not be put into the vats. Several tests were made, and in all such cases less than ·01 per cent. of indigotin was obtained from the plant.

Leaves sometimes turn black or "burn" on the growing plant, and although not in the same condition as those above mentioned they contain much less colouring matter than the green leaves. An analysis of such black leaves gave only ·13 per cent. of indigotin, whilst the green leaves from the same plant contained ·33 per cent.

Zillah and Zerat plant.—Without entering into fine distinctions,

"Zillah" plant is here understood to be that which is cultivated by the *ryot* on land which has previously grown various other crops in rotation; and "Zerat" plant to be that cultivated by the planter on factory land which for the most part has grown indigo year after year in succession with little change. These Zerat lands are periodically manured with refuse plant or "seet." It is generally recognised by planters that Zillah plant gives better results than Zerat, though I believe they have not realised how great the difference really is. Planters have frequently made trials of certain processes without taking the kind of plant operated upon into serious consideration, and yet the difference may be so great as to render such experiments altogether valueless and misleading.

In July 1901, I tested Zillah and Zerat plant from Deccaha and obtained the following results:—

Plant from Deccaha (Peeprah Concern).	Percentage of leaf.	Percentage of indigotin in leaf.	Seers 60 per cent. indigo per 100 maunds of plant.
Zillah	34·5	·50	11·5
Zerat	24·8	·35	5·8

It will be observed that the Zerat plant not only contained much less leaf, but the leaf itself was much poorer in colouring matter than the leaf of the Zillah plant. The Zerat plant only yielded half as much indigo as the Zillah.

In September 1901, some experiments with different kinds of plant (Khoonties) were made in small steeping-vats with the following results:—

Average of six tests.	Seers of 60 per cent. indigo per 100 maunds.
Peeprah Zillah	14·3
Peeprah Zerat	10·5
Jagiraha Zillah	16·2

The difference here is not so great as in the former case though it is still considerable. There is usually less difference between Zerat and Zillah in Khoonties than in the first crop. The plant operated upon in the above experiments was very full of leaf.

Perhaps the difference between Zerat and Zillah plant will be more strikingly illustrated by giving the results obtained on the large scale over an extended period.

The following table shows the results obtained in the large experimental vats at Peeprah in 1901 in all those cases when the ordinary process, without chemicals, was worked for comparison with other methods. The oxidation was done in all cases by means of a blower :—

Ordinary process, 1901.	Zillah plant.	Zerat plant.
Number of experiments	42	20
Total maunds (imperial) of green plant ..	14812	6657
Total seers (imperial) of indigo actually obtained (neglecting washings, etc.)	1443	350½
Seers of indigo per 100 maunds of plant ..	9·74	5·26
Average quality of indigo; indigotin per cent. ..	64·6	57·6
Seers 60 per cent. indigo per 100 maunds of plant	10·48	5·05

It will thus be seen that Zillah plant at Peeprah in 1901 produced rather more than double the amount of ·60 per cent. indigo that Zerat plant yielded. It seems almost unnecessary to mention that in these, as well as in all other experiments, both plant and indigo were weighed in imperial or "pucca" maunds and seers, but the custom obtains at many factories of weighing the plant in *imperial* and the indigo in *factory* maunds. Of course, I am aware that indigo is sold by factory weight, but it is not necessary, on that account, to use the two systems for calculation purposes as is often done.

I have also compiled the figures in a similar way to the above for the work done in 1902 with Zillah and Zerat plant, and these are given in the following table :—

Ordinary process, 1902.	Zillah plant.	Zerat plant.
Number of experiments	37	19
Total maunds (imperial) of green plant ..	9658	5572
Total seers (imperial) of indigo actually obtained (neglecting washings, etc.) ..	907½	244
Seers of indigo per 100 maunds of plant ..	9·39	4·38
Average quality of indigo; indigotin per cent.	60·8	55·1
Seers 60 per cent. indigo per 100 maunds of plant	9·51	40·2

The results obtained on a large scale in 1902 show a still greater difference between Zillah and Zerat plant than those of 1901.—Bearing in mind the figures given in the above tables, it is not difficult to understand the extraordinarily discordant results arrived at by various planters on trying a certain process without recognising (and such has very often been the case) the enormous possible difference in the quality of the plant operated upon. On one occasion a planter showed me the results of a series of experiments he had made with a new process, and according to his figures the ordinary method of working gave much better returns. I observed, however, that the vats in which the ordinary process was worked were loaded principally with Zillah plant, whereas the new process was worked almost entirely with Zerat. On my pointing this out, I was informed that an allowance of 20 per cent. had been made for the Zerat plant. The factory was within thirty miles of Peeprah where in 1901 (the year the trials in question were made) an allowance of 100 per cent. would have been necessary.

Taking Peeprah as a representative concern, the results obtained there in 1901-2 with Zillah and Zerat plant clearly show that Zerat lands should be used as little as possible (at all events for some years) for the cultivation of indigo.

Stripping leaf.—Instead of cutting, and putting the whole plant into steeping-vats, several attempts have been made to strip the leaf and use that only in manufacture, but hitherto the method has not resulted in a practical success. The colouring matter is almost entirely confined to the leaf, and indigo made from leaf only is of superior quality, inasmuch as the stems yield on steeping much

gummy matter which deteriorates the product. Many years ago R. Olpherts used the leaf only in steeping; it was thrown direct into crates which were carted to the factory and placed in the vats. The cost of labour, however, was considered to be prohibitive though as a set-off much less vat space was required. In addition to the cost of stripping, there is another difficulty with leaves in the ordinary process as they form a compact mass with water, and without some special means of squeezing out the liquid, there is a much greater loss than in steeping the whole plant. With the hot water or steaming processes, however (especially on the accumulative system), the difficulty does not exist, and it is with such methods of extraction that treatment of leaves only would prove of the greatest advantage. The leaf on plant which in the ordinary way fills a vat of 1,000 cubic feet would go into a space of about 200 cubic feet or say a vessel measuring 6 feet × 6 feet × 6 feet.

In 1900, H. Collingridge made some experiments on a small scale in stripping and obtained some very promising results. On July 8th he stripped some ordinary indigo plants which were in full leaf again by the 28th of the same month, when they were again stripped. The leaf was again ready on the 28th August, and for the fourth time on the 4th October. From four plants he obtained 10 chittacks of leaf on the third stripping. The leaf contained 0·4 per cent. of indigotin, so that with 20,000 plants to the acre, one such stripping should be capable of yielding 20 seers of 60 per cent. indigo per acre. From one Natal plant, Collingridge obtained 14 chittacks of leaf. On this basis, if planted three feet apart, an acre would yield from 25 to 30 seers of indigo for each stripping, and Collingridge considers that four or five strippings could be obtained annually. In 1901, I made some experiments at Peeprah with ordinary plant growing on rich soil (No. 14, Table IV) cultivated in the usual way. Good results were obtained though the new leaf did not grow as rapidly as in Collingridge's experiments. The conditions, however, were not exactly the same. Collingridge's plants were grown in a garden and planted at some distance apart, whereas in my tests the growth was very thick. On the 29th June, leaves were plucked from plants (97 in number with an average height of three feet) growing on area of one square yard. They weighed 900 grams. (=15·3 chittacks) and yielded on analysis ·40 per cent. of indigotin. This is equivalent to 30 seers of 60 per cent. indigo per acre. The plants were not again stripped until the 10th August when 170 grams. (=4·6

chittacks) were obtained. The leaf was much richer in colouring matter than at the first stripping, giving on analysis 0·78 per cent. of indigotin. This is equivalent to 18 seers of 60 per cent. indigo per acre.

Apart from stripping, these results show what an enormous yield of indigo (48 seers per acre) may possibly be obtained from a very rich soil.

In order to form some idea as to cost of stripping, a number of coolies were engaged to strip a measured area of plant near the factory; 55 men stripped 5,408 square feet in 2¾ hours, and obtained therefrom 342½ lbs. of leaf. At the same rate it would take 122 coolies to strip the plant from an acre of land in a day of 10 hours, and the product would be 2,760 lbs. (=33½ imperial maunds) of leaf. On the assumption that good plant contains 40 per cent. of leaf, it would therefore take 146 coolies working 10 hours to pluck leaf equivalent to 100 maunds of plant. At the rate of Rs. 3 per month the cost of stripping 100 maunds of plant would be Rs. 14-10, the value of about 3·3 seers of indigo. This appears to be a large amount, but if anything approaching the returns mentioned by H. Collingridge could be obtained it would certainly not be prohibitive. Moreover, by experience, the cost of stripping could no doubt be greatly reduced, and, as pointed out by Collingridge, the work could be done by women and children.

Natal and Java plant.—East African Indigo, *Indigoferra Arrecta*, known as "Natal Indigo," has been grown for some years in Java in place of the Guatemala plant (*Indigofera Oligosperma*) which had been previously cultivated. I believe this fact was first made known in India by E. C. H. Cresswell, though it was afterwards prominently brought to the notice of planters by H. A. Bailey who visited Java in 1899.

The plant has been grown with considerable success by B. Coventry at Dulsingsarai, though up to last season certain difficulties regarding its cultivation had not been altogether overcome. It is more bushy and contains much more leaf than the ordinary indigo plant of Bengal.

In August 1900, I tested the leaves of a Natal-Java plant grown by H. Collingridge at Doudpore. They yielded ·82 per cent. of indigotin, but the product was contaminated with a yellow colouring matter which many years ago I had found to be present in several samples of commercial Java indigo. At the end of October, the leaf from

the same plant gave only ·55 per cent. indigotin, but it contained very little of the objectionable yellow colouring matter. By the end of November, the percentage of indigotin had decreased to ·33 per cent. and the yellow colour had all but disappeared. One of these plants, which in August had been transplanted at Mosheri, kept in leaf throughout the cold weather, though there was little growth until the following March. In April the old leaf, of a dark-green colour, yielded ·53 per cent. of indigotin and contained no yellow colouring matter. The new leaves, of a very light green colour, gave on analysis as much as ·97 per cent. indigotin, but they also contained a large proportion of the yellow dye.

In March 1900, I sowed at Peeprah five varieties of Natal and Java seed supplied by B. Coventry, and one sample sent by H. Collingridge from Doudpore.

1. Natal seed grown in Natal.
2. Natal seed grown at Dulsingsarai.
3. Java seed (white) grown at Dulsingsarai.
4. Java seed (red) grown at Dulsingsarai.
5. Java seed (*I. Oligosperma*) grown in Java.
6. Natal seed grown at Doudpore from seed grown in Java.

The seeds took some time to germinate although frequently watered, but afterwards, the plants grew vigorously and were full of leaf. The leaves were tested for colouring matter in August and October with the following results :—

Kind of plant.	Percentage of indigotin.	
	August.	October.
1. Natal	·95	·90
2. Natal (Dulsingsarai seed) ..	·90	·85
3. Java (white)	·92	·83
4. Java (red)	1·01	·90
5. Java (*I. Oligosperma*) ..	..	·68
6. Natal (Doudpore seed) ..	..	·96

When tested in August, the samples showed no indication of yellow by the boiling-water process, though, on steeping, a small amount of yellow dye was extracted in each case. In October,

No. 3 and No. 4 behaved in a similar manner, but the other samples showed no yellow either by steeping or by extraction by boiling water.

Early in August (1901) some of the plants (*viz.* 1, 2, 3 and 4) in the above list were transplanted two feet apart. The plants drooped and appeared to die, losing much leaf, but after some weeks most of them recovered and gave forth fresh leaf. Samples of leaf were plucked at intervals and tested for colouring matter, the results of which are given in the following table :—

Natal and Java Indigo transplanted.

Date when tested.	Percentage of indigotin.			
	Natal. 1	Natal. 2	Java. 3	Java. 4
December 15th 1901 ..	·43	·44	·17	·22
January 12th 1902 ..	·37	·37	·10	·17
April 17th ,, ..	·85	·81	·54	·48
May 16th ,, ..	·60	·58	·52	·50
June 7th ,, ..	·45	·45	..	..
June 28th ,, ..	·42	·46	·56	·51
November 10th ,, ..	·33	..	..	..

It will be observed that the amount of colouring matter in all these transplanted specimens was considerably less than in the plants raised direct from seed. This may have been due to difference in soil or possibly to the transplanting having been done too late in the year, as the plants in August were about 4 feet high and many of the finer rootlets must have been injured. The seeds were sown in rich garden soil and transplanted into soil represented by analysis No. 12 in Table IV. During the cold weather months, Java plant contained very little colouring matter; afterwards, from April to the end of June, the amount remained fairly constant. The two specimens of Natal (transplanted) indigo gave rather unexpected results. Unlike the ordinary plant of Bengal, a maximum percentage of indigotin was obtained from the leaf in April, and the amount afterwards gradually decreased. Unfortunately, circumstances did not permit of tests being made in July, August and September.

Taken altogether, the results obtained from Natal-Java plants are very promising, though considerably more work is required to find out the best method of cultivation for Behar as well as the most suitable time for cutting the plant.

Polygonum tinctorium. This plant grows in temperate climates and is cultivated in Japan and parts of China for the production of indigo. It was with this plant that Schunck in 1877 continued his classical researches (commenced in 1854 with *Isatis tinctoria*) on Indican and Indigo. The work was done at Manchester, and here the plant grew vigorously in the open, producing an abundance of leaves and attaining a height of about three feet. Thinking that this plant might be grown in Behar during the cold weather, I made analyses of several specimens of *Polygonum tinctorium* supplied to me by B. Coventry. In August and September the leaves yielded on an average ·40 per cent. of indigotin. As the plant contains a much greater proportion of leaf than *Indigofera*, the whole plant would probably give quite as much, if not more, indigo than an equal weight of the ordinary plant. The plant requires a considerable amount of water and does not thrive well during the hot months in India. The cultivation of *Polygonum tinctorium* in Behar, either before or after the ordinary indigo season, is well worth closer attention.

In working with this plant, I obtained certain effects which tend to show that the colouring principle therein does not exist in precisely the same form as in the leaf of *Indigofera*. If a portion of a leaf be crushed or bruised, that part quickly becomes of a bluish-green colour. On now plunging the leaf into boiling alcohol the part affected becomes dark indigo blue, whereas the uninjured portion is decolourised or retains only a pale yellow tint. A leaf of *Indigofera Sumatrana*, treated in the same way, shows no indication whatever of blue development even after standing some hours. On immersion in boiling alcohol, the green colour is removed (though not very readily) and the crushed spots become yellowish brown.

It has already been stated that when ordinary green indigo plant is allowed to stand in a heap, fermentation sets in and the colouring matter is more or less rapidly destroyed. This is not the case, however, with *Polygonum tinctorium*. By such treatment indigo blue is developed, and to such an extent that in Japan it forms the usual method of manufacture, though the product is very crude and contains only about one per cent. of indigotin.

Isatis tinctoria.—This plant commonly known as "woad" was formerly (before the introduction of indigo into Europe) largely cultivated in England and France for dyeing blue. Schunck found the colouring principle (which he named Indican) in this plant to be identical with that in *Polygonum tinctorium*, but it is present to a much smaller extent. In March 1901, I examined some "woad" plants grown at Dulsingsarai and found the leaves to yield only about 0·1 per cent. of indigotin.

MANUFACTURE OF INDIGO.

By far the most important operations in indigo manufacture are the steeping of the plant and the oxidising of the liquid obtained thereby; but, as in former reports, it will be best to discuss the various stages of the whole process in their natural order.

Cutting the plant and carting.—I have already shown under "Colouring matter in leaf" that the colouring principle increases in the plant until late in the season, and that it is a mistake to commence cutting too early, provided sufficient vat-space is available to cope with the crop. Taking the falling of leaf into consideration, about the middle of July in normal years appears to be the best time to commence "mahai" in Chumparun and Tirhoot.

Plant is often considerably damaged by long exposure to the sun during its journey to the factory, and for this reason it is much better to have two smaller factories in place of one large one. Cutting overnight should be avoided, and in all cases the plant should be carted to the factory and put into the steeping-vats with as little delay as possible.

Loading the vats.—With good average plant, I have found about 120 Imperial maunds per 1,000 cubic feet vat capacity to give the best all-round results. Other things being equal, the more plant that is put into the vat, the greater is the proportion of liquid (and consequently of colouring matter) left in the "seet." When the plant is of poor quality, it is advisable to proportionately increase the weight per vat, and up to such an extent that with poor sticky Zerat plant I should recommend the vats to be loaded as heavily as ever possible; the reason for this being that very poor plant, with moderate loading, produces such a weak liquor that on oxidation the "mal" settles but imperfectly and a great proportion of the indigo runs away in the "seet" water. With weak liquors, there is not

only a greater *proportion* of indigo lost in the "seet" water but usually a greater *actual* loss per vat.

Extraction of the colour principle.—The extraction of the colouring principle from plant will be treated and described under four headings, *viz.*—

1. Ordinary steeping.
2. Extraction by hot water.
3. Extraction by boiling water.
4. Extraction by steaming.

1. *The ordinary steeping process.*—For this important operation a plentiful supply of good water is indispensable. Every 100 maunds of plant requires about 4,500 gallons of water, and this large volume of liquid only yields, on an average, from 8 to 10 seers of indigo. The length of time required for extracting the colour-yielding principle by ordinary steeping varies from nine to fourteen hours; ten to twelve hours may be considered a fair average period. The temperature of the water in June, July and August is usually from 88 degrees to 95 degrees F., whereas in September it often falls to 82 degrees or even 80 degrees, when a longer steeping is necessary. In my first annual report, the opinion was expressed that the active fermentation which takes place during steeping, resulting in the formation of a compound easily convertible into indigotin by the action of air, was brought about by *enzymes* (soluble ferments); and that bacteria, although present in great numbers, played but an unimportant part in the process. This opinion has since been confirmed by much detailed work conducted by Mr. C. Bergtheil at Peeprah. When the temperature of the water is raised to 150 degrees F., the extraction and conversion are accomplished in a very short time (about half an hour), and here the action can only be due to enzymes. In the ordinary steeping process, many attempts have been made to encourage and accelerate the butyric fermentation by the addition of starchy and saccharine matters, but notwithstanding assertions to the contrary, such additions to the steeping-vat are worse than useless. In a well-regulated steeping operation, butyric fermentation should be as far as possible suppressed.

It is well recognised by all planters that the length of time allowed for steeping should be varied more or less in accordance with the temperature of the air and water. Considering the com-

plexity of the changes taking place during the operation and the lack of means for determining their completion, it is astonishing how near to perfection this process is usually carried out under normal conditions.

Although certain unavoidable losses occur, I am of opinion that with good water and favourable weather there is little, if any, room for improvement in the steeping operation as generally conducted in well-managed factories in Behar. With bad water and unfavourable weather, however, the outturn is frequently very inferior, both as regards quality and quantity. It is under such conditions that improved methods will naturally be found to be of the greatest value.

Time of steeping and temperature of water.—From a great number of experiments, both on a small and manufacturing scale (which cannot well be tabulated), I have found that with water at a temperature of 90 degrees to 92 degrees F., the steeping operation should be of about 12 hours' duration. For every two degrees under 90 degrees an extra half-hour should, as a rule, be allowed; and for every two degrees above 92 degrees half an hour less should be given. If the temperature of the water is below 90 degrees F., instead of varying the time of steeping it is preferable to heat the water to that point or a few degrees higher, but not above 96 degrees F. This is best done by means of an arrangement of steam pipes in the "khajana" or reservoir. Heating the water as it passes along the "moree" is not recommended as the temperature is raised irregularly and it has been found that in this manner indigo of inferior quality is usually produced. After heavy rain, irrespective of the temperature of the water, I should recommend at least an hour's extra steeping to allow for the probable loss of enzymes.

In 1901, by raising the temperature of the water used in steeping (large vats) five degrees (85 degrees to 90 degrees) on three days, an average increase of 13 per cent. of colouring matter was obtained. Similar experiments during "khoontie mahai" of 1902 showed an average increase of 10 per cent. when the steeping water was raised five to six degrees above the ordinary temperature.

In 1888, D. N. Reid made a number of trials at Moniarah Factory with Henly's patent heating process in which the temperature of the water in the steeping-vat was raised by means of pipes heated by steam, direct fire, or by fermenting "seet." The temperature arrived

at is not stated but the steeping allowed was six to seven hours; and during "khoontie mahai" of 1888 the process is said to have given an increase of 23 per cent. It should be mentioned that the calculation was based on vat measurement and not on weight of plant.

Water used in steeping.—The chief sources of supply are river, lake and rain water. As a great portion of the soil in Behar is highly calcareous it frequently happens that rain water, collected in tanks dug out of the ground or that which collects in natural depressions forming "chours," contains as much lime and other mineral matter as the neighbouring river. Lake water varies very greatly in composition according to the rainfall. In times of drought lake water usually contains a large amount of organic matter both in solution and suspension, but after heavy rain the character of the water naturally changes.

From innumerable analyses of water used in indigo manufacture, in conjunction with experiments and observations made at various factories, I have come to the conclusion that the mineral matter present is of very little importance as a determining factor for quality; but that much depends upon the presence or absence of organic matter, especially of minute living forms. It is well known that on some occasions, frequently for days together, the "mal" after beating does not settle well and much indigo runs away and is lost in the "seet" water. This effect is usually due to the presence of great multitudes of micro-organisms whose movements prevent the indigo from settling. The addition of an alkali such as caustic soda, carbonate of soda, or ammonia to the vat partially overcomes the difficulty, but it may often be prevented by previously treating the steeping water with certain reagents or chemicals. In all cases permanganate of potash has been found to act most beneficially. The permanganate solution should never be added direct to the steeping-vat, as is frequently done with saltpetre, but should be thoroughly mixed with the water in the "kajana" at least an hour before use. In many cases the loss of indigo in "seet" water has been reduced at least one-half by treatment with permanganate. Early in the season of 1901, the water at Peeprah contained much organic matter, and the "seet" water (from the wheel range) which was greenish in colour was found to contain from 10 to 11 lbs. of 60 per cent. indigo per 1,000 cubic feet. When the same water was treated with permanganate and otherwise under the same conditions, only

4 to 5 lbs. of 60 per cent. indigo were found in 1,000 cubic feet of the "seet" water. After three or four days, heavy rain greatly improved the quality of the water and the treatment with permanganate became no longer necessary.

When a hard water is treated with softening re-agents, caustic soda, sodium carbonate, lime, etc., a more or less voluminous precipitate of calcium and magnesium carbonates is produced. It has been found that the bulk of the micro-organisms present in a water are carried down by this precipitate and thereby rendered inert. In a report dated the 20th October 1899 (which was not published), I made the following remarks on the purification of water for indigo manufacture.

Unless the water used for manufacturing indigo is of exceptionally good quality, it should be treated in large tanks or reservoirs with certain reagents or "chemicals" to remove impurities. There are various mechanical arrangements in use for purifying water, but the one devised and patented in England by Archbutt & Deeley is particularly recommended both on account of simplicity and efficiency. The object aimed at in treating water for indigo manufacture is not so much a question of mere softening as of removing organic impurities and of adding substances capable of preventing or arresting putrid and other undesirable forms of fermentation. Two or more large tanks should be arranged on a higher level than the steeping-vats, of a total capacity equal to the requirements of the day. Each tank is furnished with a series of rows of perforated iron pipes which are in communication with a steam blower. When the tank is filled with water and steam is admitted to the blower a rapid current of air is drawn through the apparatus a d the water has the appearance of being in a violent state of ebullition. In this way a perfect mixture of the water with the reagents added rapidly takes place

Most of the waters of Behar owe their hardness to the presence of bicarbonates of lime and magnesia, and such waters may be softened by the addition of limewater or milk of lime only. Others (containing sulphate of lime) require also the addition of sodium carbonate, and in some cases a small amount of alum or of alumina-ferric is required. The precipitate which is formed at first subsides slowly, but after two or three operations have been performed, the accumulated precipitate has the effect of promoting rapid subsidence and the purified water may be used half an hour to an hour

after the steam blower has been stopped. The precipitate thus formed carries down with it micro-organisms and other organic impurities which are detrimental to the production of good indigo. The amount of lime to be added to a water in order to soften it depends not only upon the quantity of earthy bicarbonates present but also upon the amount of free carbonic acid (carbon dioxide) present in solution. If either too much or too little lime is added the water may be rendered harder than it was originally. For the purpose of indigo manufacture, it is preferable to have a slight *excess* of lime; the precipitate settles more readily, and moreover a slightly alkaline water is more suitable for steeping than a neutral or an acid water.. An excess of lime is indicated by the production of a pink coloration on the addition of a few drops of phenolphthalein solution.

Broadly speaking, 1,000 cubic feet of water require half a pound of good quicklime for every grain of calcium carbonate per gallon. In addition to lime, 4 to 8 oz. of potassium permanganate should be added per 1,000 cubic feet.

When the blower is worked for 10 minutes (the usual time necessary to obtain a perfect mixture) the temperature of the water is raised about 2 degrees F. If, therefore, the temperature of the water is low, the blowing may be continued with advantage for a longer period, until it reaches 90 degrees to 92 degrees F.

Taking the present low price of indigo into consideration, many planters are of opinion that such an arrangement as above described is too expensive, but the principle might be carried out in a modified form at a moderate cost. The "kajana" for this purpose should be divided into two parts (in many factories this is already done) and the water treated in one division whilst the other (previously treated) is supplying the steeping-vats. A further modification, if desired, might be made by using a beating wheel to mix the water and chemicals instead of the arrangement of pipes and blower. The objection to treating water in the "kajana" as thus sketched is that in many factories as at present constituted the capacity of the reservoir is not sufficiently large to allow of the intermittent action being carried out. Even if arrangements cannot be made for systematically treating the water, I should still recommend planters to add milk of lime to the water as it runs into the steeping-vats, in the proportion of half a pound of quicklime per 1,000 cubic feet for every degree of hardness, or in such quantities that a

sample of the treated water becomes faintly pink on the addition of a drop of phenol-phthalein solution.

It has already been stated that mineral matter in water has very little effect upon the quality of indigo produced. This applies to the great majority of cases where the supply is either river, lake or rain water. The hardness of such waters rarely exceeds 9 degrees and is usually only from 3 to 6 degrees. I have known, however, of a water from a tube-well being used for indigo manufacture, where the hardness was as much as 60 degrees, and in addition much alkaline carbonate and free carbonic acid were present. This water produced very bad results both as regards quantity and quality; the indigo contained but 35 per cent. of indigotin and was valued in Calcutta at Rs. 60 per maund. The water was treated with lime in the proportion of 30 lbs. of quicklime per 1,000 cubic feet and a little potassium permanganate. The result was an indigo testing upwards of 63 per cent. indigotin, and it was valued at Rs. 155.

A great number of substances have been tried with a view of improving water for steeping purposes, but, in my opinion, the two simple compounds, lime and potassium permanganate, answer every requirement. They are comparatively cheap and easily obtainable. With pure water no addition is wanted, and water containing organic matter and other impurities can be rendered equal to the best by the judicious application of lime and potassium permanganate. Water from a tube-well or from a river may be below the normal temperature, and in such cases it should be heated as previously mentioned.

A number of experiments on a large scale were made at Peeprah in 1901 with water treated by the Archbutt-Deeley system, but although at the time of working a distinct benefit was shown, the actual figures obtained were not altogether convincing. On two dates the purified water produced an increase of upwards of 40 per cent., but the average of all the experiments (10 consecutive dates) only showed an increase of 6 per cent. It should be pointed out, however, that when the experiments were made (the end of July and beginning of August) the ordinary water used for "mahai" was of very good quality and a substantial increase was, therefore, not to be expected. Moreover, the difficulty was still further enhanced by not being able to obtain plant of a regular quality as was clearly shown by the divergent results frequently obtained when precisely

the same mode of treatment was followed. Unfortunately, at the commencement of "mahai" when the water was at its worst, the purification tanks were not ready for use.

At the commencement of "mahai" in 1902 arrangements were made to repeat the experiments of the previous season with purified water. After one day's trial, however, heavy rain caused the naturally pure "Narsey" water to flow into the pump-well, and it was no longer possible to obtain a supply of the impure lake water for a continuation of the experiments. On the one day in question, the purified water gave an increased yield of colouring matter of 12 per cent.

Notwithstanding the lack of direct evidence as to the improvement in manufacture by water purification, I can confidently recommend the treatment with lime and permanganate in the proportions already given whenever the water is of an inferior quality. Moreover, if there should be any doubt regarding the quality of the water, the addition of these substances can do no possible harm.

Saltpetre in steeping.—Planters have used saltpetre with more or less satisfactory results for many years. The general opinion is that saltpetre improves the quality of the indigo and causes the work to proceed more easily and rapidly, but as regards increase of colouring matter, the reports of different planters are conflicting.

From numerous experiments in small vats and in the laboratory, I have found that saltpetre does not produce any real increase of colouring matter. In these small-scale tests, actual increase of colouring matter only can be taken into account. For general working, including subsidence of "mal" and indigo produced, experiments in small vats and in the laboratory are of little or no value.

Series of trials in large vats were made at Peeprah both in 1901 and 1902.

In 1901 six tests were made, using 25 lbs. of saltpetre per 1,000 cubic feet in each case. The liquid obtained was oxidised by means of a Korting's blower and the following results were obtained :—

Average of six tests.	Seers 60 per cent. indigo per 100 maunds of plant.	Increase per cent.
Ordinary steeping	13·22	..
Steeping with saltpetre	15·00	14·2

Taking the value of indigo at Rs. 4 per seer, saltpetre in these experiments, at a cost of Re. 1-5, produced an increased amount of indigo worth Rs. 7 per 100 maunds of plant. Calculated on the pucca vat, saltpetre at a cost of Rs. 4 produced an increase of indigo worth Rs. 21.

Whenever saltpetre is used in steeping, the operation should be continued for about two hours longer than usual.

It has been stated that on a small scale saltpetre produced no actual increase of colouring matter, from which it might be reasonably inferred that the increase obtained in large vats was due to better settling of the "mal" after beating. For this reason, I stated in my report of the 15th May 1902 that there would probably be no advantage in using saltpetre in the steeping-vat in conjunction with caustic soda or ammonia, as these substances also prevented loss, and to a higher degree than saltpetre. This opinion was confirmed by a series of experiments in 1902. Steeping was made with and without the addition of saltpetre to the water, and in all cases caustic soda (in the proportion of 20 lbs. per 1,000 cubic feet) was added to the oxidising vat. The results obtained are given in the following table :—

Average of four tests. Caustic soda used in all cases in oxidising.	Seers 60 per cent. indigo per 100 maunds of plant.	
	From analysis of vat liquor, allowing for loss in seet water.	Actual weight of indigo obtained and weighed dry.
Ordinary steeping	13·24	12·25
Steeping with saltpetre	13·16	11·75

It will be seen that ordinary steeping and steeping with saltpetre (in conjunction with caustic soda in the oxidising vat) gave practically the same results according to figures obtained by analysis of the vat liquors, but from the actual weighing of the indigo produced, saltpetre gave a distinctly smaller yield. This difference I attribute to the fact that each day 4,000 cubic feet of vat-space were worked " ordinary " and only 2,000 cubic feet with saltpetre. Under such conditions, I subsequently found that with exactly the same process the larger amount of plant operated upon invariably gave a greater yield of indigo. The difference is, undoubtedly, due to the greater relative loss in filtering and pressing (table and press sheets) with smaller quantities than with larger amounts. It is not, of course, an actual loss to the factory since the bulk is recovered as " washings," but as far as experiments are concerned the loss is a serious one, and I believe has often been the cause of erroneous conclusions having been drawn by planters regarding the value of certain processes. I shall have occasion to refer to this matter again under another heading. The results obtained by analysing the oxidised liquor and " seet " water are not in any way affected by the greater or smaller amount of plant operated upon. The method is far more reliable and accurate than that of weighing the dry indigo ultimately obtained. At the very best the so-called practical way of weighing the indigo is a very crude one, and as I have often pointed out, there are many loop-holes for possible errors to creep in and vitiate the results. Loss must necessarily occur between the pumping up of the " mal " into the boiler and the weighing of the dry indigo. The loss is not by any means a constant one, and in consequence a process may appear to give an increase when there is no real increase, and *vice versa*. Except in very rare cases (experiments in boiling) the operations after oxidising and settling of the " mal " have nothing whatever to do with the process being tried, and therefore, if possible, they should be eliminated.

During " khoontie mahai," of 1901 and the whole of 1902 " mahai," the method of analysing the oxidised liquor and " seet " water was invariably carried out, and although in all cases the dry indigo was finally weighed carefully and tested, yet greater reliance is placed upon figures obtained by the former mode of procedure.

In 1902 steeping experiments were also made with saltpetre alone and in conjunction with sodium carbonate in the oxidising vat. The results are shown in the following table :—

Average of four tests.	Seers 60 per cent. indigo per 100 maunds of plant.	
	From analysis of vat liquor, allowing for loss in "seet" water.	Actual weight of indigo obtained, and weighed dry.
Saltpetre in steeping. No addition to oxidising vat	13·40	13·00
O·dinary steeping. Sodium carbonate to oxidising vat ..	14·11	13·08
Saltpetre in steeping. Sodium carbonate to oxidising vat ..	14·34	13·10

In this series of experiments, the amount of plant treated each day was the same in every case, *viz.*, 2,000 cubic feet. When sodium carbonate was used, 28 lbs. per 1,000 cubic feet were added to the vat.

It should be pointed out that when these experiments were made, the water used in steeping was of excellent quality, and it might with reason be contested that under other conditions saltpetre would show to greater advantage. No opportunity presented itself, however, to allow of the experiments being repeated with bad water.

Carbolic acid in steeping.—This well-known antiseptic was used in the proportion of 2 gallons per 1,000 cubic feet and tried on six days in 1902. The addition was made (as with other antiseptics mentioned below) with a view of preventing or retarding putrefaction without at the same time interfering with the useful action of bacteria and enzymes on the colouring principle. As will be seen from the results given in the following table, carbolic acid in steeping had practically no effect :—

Average of six tests.	Seers 60 per cent. indigo per 100 maunds of plant.	
	From analysis of vat liquor, allowing for loss in "seet" water.	Actual weight of indigo obtained, and weighed dry.
Ordinary steeping	13·98	13·10
Steeping with carbolic acid ..	14·24	12·95

Mercuric chloride in steeping.—Mercuric chloride was added to the steeping water in the proportion of 1 lb. per 1,000 cubic feet and tried on four days. It is evident from the results tabulated below that this powerful disinfectant, even in such small proportions, had a deleterious effect in steeping :—

Average of four tests.	Seers 60 per cent. indigo per 100 maunds of plant.	
	From analysis of vat liquor, allowing for loss in "seet" water.	Actual weight of indigo obtained, and weighed dry.
Ordinary steeping	14·34	13·80
Steeping with mercuric chloride ..	12·43	11·40

Formaldehyde in steeping.—Experiments with this comparatively new antiseptic were not made on the large scale, but several tests under various conditions were made in the laboratory. Even in small quantities (in the proportion of 2 lbs. per 1,000 cubic feet) it was found to have the remarkable property of entirely preventing the formation of indigo either with ordinary or prolonged steeping.

Potassium permanganate in steeping.—This compound also was only tried on a small scale, as in very small proportions it was found to have an injurious action on the colour. With 2 lbs. per 1,000 cubic feet of water, less than half the normal amount of indigo was produced.

The small quantity of permanganate recommended for purifying water, however, does not act injuriously. The bulk, if not all, is destroyed by the organic matter present, and if any trace remains it gradually decomposes (as shown by the disappearance of the pink colour) on standing.

Lime and alkalies in steeping.—In dyeing with indigo, one of the oldest ways (and still the best) of rendering the colouring matter soluble is by means of fermentation. The finely ground indigo is mixed with certain proportions of farinaceous matter (bran, flour, etc.) or substances containing glucose, such as treacle, dates, etc. Lime (and in some cases potash or soda) is also added to the mixture; it serves a double purpose. The farinaceous and saccharine matters undergo fermentation with the production, among other bodies, of butyric acid and hydrogen. The lime neutralises the acid and thereby checks putrid fermentation. It also dissolves the "reduced" indigo formed by the action of nascent hydrogen upon the colouring matter. Finally, a greenish-yellow solution is obtained, in many respects similar to, but not identical with, the liquor obtained on steeping indigo plant. Since lime (or other alkali) is essential for the success of this operation, it was thought, by analogy, that it might be of material benefit in the steeping process, and many experiments have been made on a small scale with this object in view. The expectations, however, were never realised although, as has been previously stated, water *slightly* alkaline is more suitable for steeping than a neutral water, and much more so than water containing free carbonic acid gas.

From the results of a great number of experiments, I have found that the amount of lime present in water used for steeping should not exceed 5 lbs. per 1,000 cubic feet. This should not be construed as meaning that more than 5 lbs. of lime should never be added to 1,000 cubic feet of water. It refers to the excess of lime after the carbonic acid (free and as bicarbonates) has been neutralised.

In place of lime, experiments were also made with magnesia and soda-ash (sodium carbonate), but these substances offered no advantages over lime.

In connection with this matter, I may state that the process described in Ernsthausen's patent specification No. 213 of 1899 consists essentially of the addition of alkali or soda-ash to the steeping-vat. In the first place a little mercuric chloride only (2 to 4 oz. per 1,000 cubic feet) is added to the water used in steeping. After the 7th or 8th hour of fermentation, a solution of 164 to 180 lbs. of an alkaline mixture per 1,000 cubic feet is run into the vat and distributed by means of a perforated pipe lying across the bottom. The steeping is allowed to proceed for about 18 hours instead of the usual 10 to 13 hours. The alkaline mixture is described as consisting of 40 parts of carbonate of potash, 40 parts of carbonate of soda (soda-ash), 15 parts of nitrate of soda and 5 parts of sugar. It is not at all likely that the two latter substances can play any part in the process, and there can be no possible reason for using carbonate of potash as well as, or in place of, carbonate of soda. It is further stated in the specification that the alkaline mixture may be added either to the beating vat or to the steeper, or partly to both.

Seeing that Mr. E. C. Schrottky, in a circular addressed to indigo planters dated 18th June, 1901, claimed exclusive privilege for the joint use of alkalies and acids in virtue of the above patent (No. 213 of 1899); and that Mr. M. H. Mackenzie in a letter of the 12th September, 1901 (which was printed and circulated), referred to the method of working which he had used as "Schrottky's combined alkali and acid process," it is only reasonable to assume that the trials made at Rajkund in September, 1901, were carried out in accordance with, and under the protection of, Ernsthausen's specification. By working the alkali and acid process six days, Mr. Mackenzie obtained an average of 21·5 seers of "produce" per 100 maunds of green plant, and considering that 12½ seers per 100 maunds was a fair average under ordinary conditions, he estimated that the new process gave an increased yield of 13½ seers of indigo per 1,000 cubic feet of vat-room. The letter containing these statements was widely circulated, and yet the *quality* of the indigo produced had been altogether ignored. Afterwards the samples were sent to me for analysis; on the 29th September, 1901, I wrote to the General Secretary of the Association on the subject, and the following is an extract from the letter :—

"During the six days' trial with Mr. Schrottky's process, the average amount of indigo produced, according to calculation

weights, was 21·3 seers per 100 maunds of plant. Mr. Mackenzie in his letter of the 12th instant stated that he considers under ordinary conditions 12½ seers of indigo per 100 maunds would have been produced, and on this basis estimated the increase obtained by the process. But on the two days immediately following the trials, the ordinary process actually gave (according to figures since submitted) 16·9 and 16·4 seers respectively per 100 maunds. I have analysed the samples representing the indigo made by the patent process from the 3rd to the 8th September (inclusive) and two samples representing indigo made by the ordinary process on the 9th and 10th September, and have obtained the following results :—

	Percentage of Indigotin (and indirubin) on the perfectly dry indigo.	
September 3rd No. 256 Patent	.. 40·4	Average 36 per cent.
,, 4th ,, 257 ,,	.. 37·5	
,, 5th ,, 258 ,,	.. 38·8	
,, 6th ,, 259 ,,	.. 36·5	
,, 7th ,, 260 ,,	.. 31·4	
,, 8th ,, 261 ,,	.. 31·4	
September 9th No. 62 Ordinary	.. 53·4	Average 54 per cent.
10th ,, 64 ,,	.. 54·6	

"As already mentioned, according to calculation weights, the six lots of "patent" indigo gave an average of 21·3 seers per 100 maunds, and the two lots of "ordinary" 16·66 seers for 100 maunds. Taking the quality, however, into account, and expressing the "produce" in terms of 60 per cent. indigo, we obtain the following figures :—

Average of six days' Patent—12·8 seers 60 per cent. indigo per 100 maunds.

Average of two days' Ordinary—15·0 seers 60 per cent. indigo per 100 maunds."

In a similar manner trials were made at Dholi in July, 1901, and without having the indigo tested statements were circulated by the agents that the Patent Process had given an increase of 107 per cent.

Afterwards, as in the previous case, the indigo was analysed and the following results were obtained :—

Patent Process—25·2 per cent. indigotin on the dry.
Ordinary Process—54·6 per cent. indigotin on the dry.

This difference rather more than compensates for the 107 per cent. increase in quantity.

Double or second steeping.—After ordinary steeping and running off the liquid, the refuse plant is saturated with a solution of the colouring matter which is lost. This loss amounts to about 5 per cent. of the total colouring matter. Washing the refuse plant afterwards with water is of no avail since the colouring matter is rapidly decomposed as the liquid runs away. The temperature of the wet refuse plant rises rapidly, indicating that some vigorous form of fermentation takes place. In 1901 some experiments were made with a view of recovering the colouring matter left in the plant after steeping, but the results were not successful. After the usual steeping, the vat-valve was opened and at the same time fresh water was allowed to flow in and spread over the surface of the plant at such a rate as to maintain a constant level. The plant was allowed to steep for a further period of two hours and the "mal" obtained from both steepings collected and treated in the usual way. Five tests were made, and on each occasion the "double steeping" gave less indigotin (varying from 12 to 20 per cent.) than the ordinary steeping.

Some twenty years ago, according to the testimony of several planters, E. Schrottky obtained some very satisfactory results by means of a second steeping, but beyond a few experimental trials the process was not adopted. In a leaflet circulated in December 1900, Schrottky pointed out that the process had formerly been abandoned on account of its successful working depending too much on constant and unremitting European supervision, but by means of an invention patented in 1899 it was much simplified. In the same leaflet, Schrottky also claimed the discovery of a second true indigo fermentation induced by the addition of "certain chemicals," whereby an increased yield of 120 to 150 per cent. of indigotin was obtained. It was recommended to treat the first steeping and liquor obtained therefrom without the use of chemicals, and keep the product separate from that obtained from the second steeping by the use of chemicals.

Ernsthausen's process (patented 1899, No. 213) and Schrottky's so-called Pastau's process appear to be variations of the above, but in these cases one steeping only is mentioned.

2. *Extraction by hot water.*—When indigo plant is immersed in water at a temperature of 150 degrees to 160 degrees F., the colouring principle is quickly extracted and transformed through the agency of enzymes, (unorganised ferments) into a form of indoxyl which is converted into indigotin by the action of air. Experiments made on a small scale have shown that the extraction and transformation take place in the course of twenty minutes or half an hour. In 1892 A. Schulte im Hofe was granted a patent No. 157 for manufacturing indigo on these lines, and the process was worked with more or less success at Sahti and other places. The steeping was allowed to proceed for 1½ to 2 hours at a temperature of about 140 degrees F. Indigo of superior quality (similar to Java) was obtained but the yield was below the normal, and the difficulty of maintaining the correct temperature was found to be very great. Moreover, the cost of fuel was a serious item. Bridges-Lee, in his little book on indigo manufacture, also describes the hot-water process and claims the method mentioned therein as his own. The book is dated 1892, the same year in which Schulte's patent was granted. Schulte heated the water to the desired temperature in a separate vessel before running it on to the plant, but Bridges-Lee loaded and watered the vats as usual and then applied heat by means of a fire or steam pipes at the bottom of the vat. The heat was so applied as to raise the temperature of the liquid to 150 degrees or 160 degrees F. during the course of an hour to an hour-and-a-half. After standing ten minutes longer, the vat was opened and the liquor at once beaten. When using the hot-water process, it is important to bear in mind that the liquid should always be immediately oxidised, otherwise changes rapidly take place resulting in the loss of much colouring matter.

From the description given by Bridges-Lee it is evident that he viewed the operation as one of mere extraction, and that he did not realise the important part played by enzymes during the process.

In Henly's "heating process of 1888," referred to under "Time of steeping and temperature of water," the method of heating the vat is similar to that described by Bridges-Lee, but the process is entirely different. An alternative method of heating the vat, given

by Henly, consisted in placing fermenting seet round it, showing that a moderate increase of temperature only was desired, as is also shown by the fact that a period of six or seven hours was allowed for steeping.

Returning to the "hot-water" process, by which term extraction at a temperature of 150 degrees F. or thereabouts is understood, I was, from the commencement of my investigations, much impressed by the outlook it presented, as it seemed to be capable of giving indigo of excellent quality, uniform in character, and free from the ever-varying conditions under which the ordinary steeping process is subjected. After several promising laboratory tests at Mozufferpore and Mosheri, the first real trials were made in 1889 in vats of 100 cubic feet capacity. The bottom of the vat was fitted up with perforated steam pipes; after loading with plant and watering in the usual way, steam was admitted until the temperature reached 150 degrees to 155 degrees F. The liquid was allowed to stand for 15 to 20 minutes, when it was run off and at once oxidised. The actual weight of "produce" obtained was always less than that yielded by ordinary steeping, but it was of far superior quality. Calculated into terms of 60 per cent. indigo, there was scarcely any difference, though on two or three occasions the "hot-water" process showed an increase of 5 to 10 per cent. This was not much, though if the cost were not prohibitive, it was a step in the right direction as the yield was regular and could be depended upon irrespective of changes in climatic conditions.

The indigo made by hot-water treatment tested 75 to 77 per cent. and that made in the ordinary way tested 50 to 55 per cent. These latter figures for ordinary process indigo may appear unusually low, but I should point out that indigo made in small experimental vats is almost invariably of rather inferior quality. This no doubt accounts for statements made to me by planters that trials made in small experimental vats have often resulted in very large yields of indigo, *crude* indigo, be it understood, as the percentage of colouring matter was never taken into consideration.

On account of the expense of fuel, I came to the conclusion that in order to be a practical success the hot-water process would have to be worked on the "accumulative" system, such as is followed in the extraction of dyewoods, tanning, etc., and in the diffusion process of sugar manufacture.

I made numerous laboratory tests on these lines in 1900, and

obtained some very satisfactory results, but it was not until October 1901 that I was able to carry out the idea on anything like a practical scale.

The apparatus devised for the purpose consisted of a battery of four iron vessels or "kiers," each having a capacity of 35 cubic feet, doubly connected with each other and provided with pipes for the introduction of steam. On the 19th September, 1901, I applied for leave to file a specification of a patent for this apparatus, but for some reason or other the application was not granted. The following is a description of the method of working with the apparatus.

In commencing the operation, the first vessel is filled with plant, the lid closed, and water at the desired temperature run in from an overhead tank. After steeping 1 to 2 hours a fresh lot of water is run in and the steeped liquid forced into the second vessel containing fresh plant. This is repeated until the last "kier" in the series is reached, when the liquid is run off and oxidised. At this stage the continuous working of the process is established and becomes regular. The contents of the first vessel are discharged and fresh plant introduced. After the next steeping or maceration it becomes the last of the series, and "kier" No. 2 is discharged and filled with fresh plant. Clean hot water enters each vessel in succession, and each vessel in turn becomes the one filled with fresh plant, from which the strong decoction is always withdrawn. The temperature of the liquid is maintained by the admission of steam under a false bottom consisting of perforated iron plates. Each vessel or "kier" is provided with a suitable thermometer. The solution obtained is run into a tank or vat and immediately oxidised, preferably by means of a steam blower.

A number of trails were made in this apparatus during 1901. The plant at this period was of but poor quality, containing only about 20 per cent. of leaf. At the end of September it yielded, by the ordinary process, from 6 to 7 seers of 60 per cent. indigo, per 100 maunds. The whole of the colouring principle was obtained from the plant by three waters, indeed the third extraction, as a rule, contained mere traces of colour. In the oxidising vats the "mal" did not settle well, and as a rule little more than half the amount of indigo produced was actually obtained in a tangible form. As a means of thoroughly extracting the colouring matter, the apparatus proved in every way highly successful, but its practical utility for

the economical production of indigo was not established. It was decided to try the process on a large scale, and in 1902, to carry this into effect, an ordinary steeping vat of 1,000 cubic feet capacity was divided into two compartments. The two vats thus formed were provided with air-tight-fitting iron covers in which suitable doors were inserted, and perforated iron plates were arranged as a false bottom. In connection with a large overhead tank a series of pipes with valves were so arranged that the liquid could be forced by displacement from either vat to the other or into a third vat to be oxidised.

A few experiments were made in July, but from want of sufficient steam power the work had to be postponed until the end of "morhan mahai" (4th August), when the trials were continued for about 10 days, though there were frequent interruptions from want of fuel and other causes.

Although the work was not carried out under the most favourable conditions, I was quite convinced that the process could never be a practical success. Less indigo was invariably produced than was obtained by the ordinary steeping process tried at the same time. Much of this was due to incomplete settling of the oxidised "mal," but even if this could be overcome (and no doubt it could), the outlay for plant, the difficulty of working in closed vessels (especially removing the hot "seet" therefrom), and the expense of steam would, with the present low rates for indigo, prove insuperable barriers to the successful working of the operation.

For some unaccountable reason the results obtained in this large vat arrangement were never so good as those obtained in the "kiers" or on a small laboratory scale.

Working on a manufacturing scale, superior results were obtained in open vats with a simple arrangement of perforated steam pipes at the bottom. This method (previously mentioned on page 48) was tried on August 19th and 21st in vats of 1,000 cubic feet capacity. The vats were loaded with plant and watered in the usual way. Steam was then admitted by a 2-inch pipe and in two hours the temperature rose from 88 degrees to 160 degrees F. The steam was then turned off, and after standing 20 minutes the vat valve was opened and the liquor at once oxidised.

On both days the hot-water treatment produced 5 per cent. more indigo (calculated in terms of ·60 per cent. indigo) than the ordinary steeping. Both lots of hot-water indigo tested when dry 75 per

cent. indigotin, whereas the ordinary process indigo tested 65 per cent. on one day, and only 60 per cent. on the other.

Regarding the cost of the hot-water process, I have found that in order to raise the temperature of 1,000 cubic feet of water from 85 degrees to 160 degrees F. about 7 cwts. of coal are required. The cost of this amount of coal in Behar is about Rs. 4, equivalent in value to about one seer of indigo.

As regards the amount of indigo obtained or obtainable, the hot-water system offers no advantage over the ordinary steeping process when the latter is carried out under the most favourable conditions; but in wet weather the process would well repay the cost of steam. In any case, when carried out by one simple hot-water extraction (as just described), indigo of a superior and uniform quality is invariably obtained, and this fact should be of especial interest to those planters in charge of factories noted for producing bad colour. With one simple extraction, a small amount of colouring matter is left in the residual plant, but my experiments with the accumulative system conclusively prove that it does not pay to recover that loss. Moreover, when a hot decoction of the colouring matter is passed over plant for a second time (as in the accumulative system) the indigo resulting from oxidation of that liquid settles badly and is always of inferior quality.

The hot-water process carried out in ordinary steeping-vats (with perforated pipes at the bottom) deserves the close attention of planters. Worked in connection with ammonia gas in beating, almost the theoretical yield of indigo may be obtained from the plant, irrespective of the weather. It has already been stated, but will bear repetition, that the indigo produced is of very superior and uniform quality.

The vats could easily be worked twice, if not three times, a day. Perhaps an objection might be raised on account of the process requiring a considerable increase of boiler power as undoubtedly it would in most factories.

3. *Extraction by boiling water.*—When indigo plant is subjected to the action of boiling water, a pale brownish yellow solution, without fluorescence, is obtained. Unlike the liquid produced on steeping and that yielded by water at 150 degrees F., the solution exhibits no sign of blue scum nor is indigotin developed by subjecting it to a current of air or oxygen. The temperature of boiling water destroys all bacteria as well as enzymes, and the solution obtained

under such conditions contains the original glucoside, presumably in the form that it existed in the plant. This glucoside is split up with the formation of indigotin by the combined action of an acid and an oxidising agent, such as potassium chlorate or ferric chloride; or by the action of certain bacteria or enzymes under suitable conditions.

Many years ago, Schunck and Romer showed that indigotin was formed from indican by the action of an acid in the presence of an oxidising agent, and the principle of the operation was subsequently applied to the manufacture of indigo in Java by Hazewinkel. In May, 1900, Hazewinkel applied for leave to file a specification in India for this process. About the same time Coventry made a similar application, but neither was granted. In both cases the oxidising agent recommended was potassium chlorate and in both cases conversion of the glucoside into indigotin by means of bacteria or enzymes was given as an alternative method.

I made some experiments with the boiling-water process in 1901 and 1902 with the "kier" apparatus already mentioned. Potassium chlorate was found to be a very unsatisfactory oxidising agent as a slight excess caused a destruction of indigo. Much superior results were obtained by ammonium persulphate which, however, will be more fully described under extraction by *steaming*. The boiling-water process could only be worked advantageously on the accumulative plan, and, in my opinion, with present indigo prices the cost of such a system would be altogether prohibitive. I got an estimate from Mr. Minchin of a diffusion battery (such as is used for sugar) to deal with 30,000 cubic feet of plant in 24 hours. Exclusive of erection and of boilers and engines, the estimated cost was Rs. 92,000.

4. *Extraction by steaming.*—This process I first investigated on a small scale at Mosheri in 1900 and worked at it subsequently at Peeprah, using the battery of "kiers" for the purpose. It consists in passing a current of steam through the plant and then filling up the vessels with hot water. The bacteria and enzymes are most effectually destroyed, and a solution of indican containing but few impurities is thereby obtained. I was granted a patent (No. 418) for this process in 1901. The indigo plant is packed in a vat or tank provided with a perforated false bottom underneath which a number of jets are arranged for the introduction of steam. Steam is turned on and allowed to blow through the plant for a period of 15 to 20 minutes, when water at a temperature of 140 to 160 degrees F. is ad-

mitted until the plant is covered. After standing for about 20 minutes the solution of indican thus obtained is run off for further treatment. In order to extract the whole of the colour principle and at the same time to keep the solution as concentrated as possible, the accumulative system is adopted. Fresh water at a temperature above mentioned is run on to the partially exhausted plant, and after standing 15 to 20 minutes this solution is run into a vessel containing fresh plant which has already been steamed as above described. The resulting liquid does not yield indigotin by being subjected to a current of air or by the ordinary beating process, but the colouring matter is produced by the combined action of an acid and an oxidising agent, or by the action of certain bacteria or enzymes as mentioned in the boiling-water process.

In connection with this method of extraction, I worked out a new process of oxidation for which I was granted a patent (No. 173) in 1902. The solution of indican obtained by steaming (or by any other process) is run into lead-lined or other acid-resisting vessels and treated with acid and an alkaline persulphate. For every 100 maunds of indigo plant operated upon, 20 seers of sulphuric acid (or equivalent of hydrochloric acid) and 20 seers of ammonium persulphate (or equivalent of other persulphate) are added to the solution. The sulphuric acid is added at once, but the persulphate is preferably divided into three or four portions and added at intervals of about half an hour; the liquid being agitated at each addition. In order to test if sufficient oxidising agent has been employed, a little of the filtered liquid is treated with a few drops of a solution of ammonium persulphate, and if any blue colour is developed a further quantity is added to the bulk. The precipitated indigo thus obtained is collected and treated as usual.

Although excellent results were obtained in the laboratory, yet on a manufacturing scale my expectations were never realised. There was no difficulty whatever in extracting the whole of the colouring principle from the plant, but the indigo actually obtained was always of inferior quality and was less in quantity (as real colouring matter) than the yield by ordinary steeping. There is no doubt that further research would enable one to overcome the difficulties, but in 1902 circumstances interfered with and prevented a continuation of the work. I should point out, however, that even if entirely successful, ammonium persulphate (at present prices) would be too costly for manufacturing purposes.

It has often been said as a kind of slur on planters and those interested in indigo manufacture that the fermentation which takes place in the ordinary steeping-vat is allowed to proceed in an empirical manner; that little is known regarding the length of time which should be given to the operation under varying conditions, and that no reliable means are known of determining its completion. Such statements are to a certain extent correct, but as I have mentioned in another place it is astonishing how near to perfection the process is generally carried out under favourable conditions. Beyond what I have already stated as to time and temperature, I see no possibility of putting into the hands of planters an indicator by means of which the steeping process could be controlled and conducted on more scientific lines under adverse conditions. The process cannot be compared with the fermenting of a homogeneous liquid such as in brewing; it is far more complex. If the colouring principle were extracted from the plant by boiling water or preferably by steaming, it would be quite possible to ferment the resulting liquid by pure cultures of bacteria or by enzymes in a systematic and scientific manner. In 1902 C. Bergtheil, the bacteriologist, did much useful and valuable work in this direction, and it is to be regretted that arrangements were not made for him to carry out his ideas on a manufacturing scale during the past season. Whether it would ultimately repay the planter to reconstruct his factory and work on such lines as those indicated, is another question. Taking into consideration the position of the industry, and also bearing in mind the improvements which have been made in the old method of working, I scarcely think it would be advisable for planters to entertain the idea of making such a complete change. The improvements to which I particularly allude are, firstly, purification of the water; secondly, raising the temperature of the steeping water when necessary; and thirdly, making use of the ammonia-gas process in oxidising.

B. *The oxidising or heating process.*—The liquid running from the steeping-vats varies in colour from a rich, bright orange to an olive green, and possesses a peculiar fluorescence. It contains about 0·50 per cent. of dry solid matter, of which only about one-twentieth part is convertible into colouring matter. The active ingredient is indoxyl formed, through the agency of enzymes, by the decomposition of a glucoside similar to, if not identical with, Schunck's indican.

The operation of "beating", however performed, is a process of oxidation, and the change which takes place may be represented by the following equation :—

$$2\ C_8H_7NO + O_2 = C_{16}H_{10}N_2O_2 + 2\ H_2O$$

(indoxyl) (indigotin)

Up to 1900 the process of oxidation was generally carried out in Behar Indigo Factories by means of a beating-wheel, though in some few places the older system of beating by hand still existed. Other methods had been tried such as that of pumping in air according to Geneste's patent of 1888, the shower-bath arrangement patented by Bridges-Lee in 1891; various devices for pumping the liquid to an overhead vat and allowing it to traverse a long inclined plane provided with projections to break up the liquid and thus expose a greater surface to the air: numerous trials had been made of these methods and other modifications of them, but although in many cases excellent results were said to have been obtained, the methods were not adopted, and as already stated, wheel-beating still remained in general use.

Oxidising by steam-blowers and air-compressors.—Having had occasion to use steam-blowers for oxidising purposes before going out to India, it occurred to me that they would be serviceable for this operation in indigo manufacture. Accordingly, I took out with me two small Deeley's blowers for experimental use, and these were installed at Mosheri in 1899. A half-inch blower was used for small vats of 100 cubic feet capacity, and an inch blower was arranged with the necessary perforated piping for a vat of about 800 cubic feet capacity. In the small vats the blower worked admirably, the oxidation being completed in 15 to 25 minutes against about two hours required for hand-beating. In the larger vat, although an increased amount of indigo was obtained compared with hand-beating, the blower was found to be too small for the purpose, the operation required rather more than two hours for completion. During "khoontie mahai" the liquor from two steeping-vats was intimately mixed and divided equally between two beating vats. In one vat the liquor was oxidised by means of the blower and the other vat was beaten by six or eight men. On five days both vats were worked without "chemicals," whilst on twelve other days various additions of an alkaline character (lime, caustic soda, ammonia, etc.) were made to the blower vat.

On the five days without chemicals, the blower produced an average increase of 25 per cent. compared with hand-beating. With the addition of lime, caustic soda, and ammonia to the "blower" vat an increase of 30 to 40 per cent. was obtained. In November, 1899, I was granted a patent for this process of oxidation, and the following is an extract from the specification :—

"The beating-vat is furnished with a number of rows of perforated iron pipes which lie at the bottom of the vat or are connected by means of a vertical pipe to the lower end of a steam-blower. When steam is admitted to the blower a powerful current of air is drawn through the pipes and bubbles up through the liquid in the vat. The whole liquid has the appearance of being in a violent state of ebullition, oxidation rapidly takes place, the "mal" settles more quickly and more completely than under the ordinary beating arrangements, and a greater yield of colouring matter is obtained. Moreover, if the blowing is continued beyond the required period for oxidation, no injurious effect is produced. During the operation the temperature of the liquor rises 10 to 15 degrees F."

Some months later I discovered that C. Geneste had previously been granted a patent for an invention of a similar character. In 1900 the process was partially adopted at several factories, but unfortunately in most cases the installations were far too small to be of any practical use. Whilst I was in England arrangements were made with the local Engineers to fit up piping and blowers (possibly from some misunderstanding) of less than half the size I had recommended, and in consequence much dissatisfaction was found with the process. The same mistake was made at Mosheri in fitting up an experimental range of 6,000 cubic feet, though after much loss of time, more powerful blowers were obtained Arrangements were not made for comparing blowers with ordinary wheel-beating, and in 1900 the work at Mosheri was principally confined to making various additions to the oxidising vat with a view of still further increasing the yield. From the work which had been done the previous year (1899) a substantial increase by "blowing" was considered an established fact, though from subsequent conflicting reports made by various planters it is to be regretted that arrangements were not made for thoroughly testing the "blower" process against wheel-beating. Comparisons were indeed made with the indigo produced in the ordinary wheel-beating range of the factory, but as the question of the quality of plant comes into play the results are

not altogether reliable. On seven consecutive days (15th to 21st July) the produce from the blower range was on an average 30 per cent. greater than that obtained by wheel-beating. Taking the whole season, however, the average increase by the blower (without chemicals) was only 11 per cent. compared with the wheel.

The only way of making a thorough trial was to divide the liquor obtained on steeping equally between the wheel-beating range and the blower vats as had been done in the previous year on a smaller scale in the hand-beating tests. But, as already stated, these arrangements were not made.

Some further tests were made with the blower against hand-beating and an average increase of 20 per cent. was obtained.

In order to show the difference between small inefficient blowers as had at first been arranged at Mosheri and more effective blowers, a number of tests were made. In each series of experiments six vats of 1,000 cubic feet capacity were used; three fitted up with 1¼ inch blowers and the other three with two such blowers in each vat. As a rule the single blowers required 2½ hours to complete the oxidation, whereas with two blowers the operation was usually finished within the hour. Six tests were made, and the result was an average increase of 22 per cent. in favour of the more rapid and efficient blowing.

The same year a large No. 8 Korting's blower was used at Rajpore factory. During the whole "mahai" the blower range gave an increase of 28 per cent. compared with the ordinary wheel range. On some days, however, certain "chemicals" were added to the blower range, which no doubt accounts partly for the large increase obtained.

At Seeraha a Tilghmann's air-compressor was used in place of a steam blower, and compared with a large wheel range it gave an average increase of 20 per cent. without the addition of chemicals to either vat

In 1901 the blowing process was introduced into numerous factories in place of the wheel; in some places steam-blowers were used and in others air-compressors. As was only to be expected results of a very varying nature were reported by different planters. Some obtained considerably better results than those mentioned above, whilst others, on the contrary, contended that the process gave no increase whatever.

The preponderance of evidence, however, was decidedly in favour

of a substantial increase being obtained, and all were unanimous in declaring that the subsequent operations of manufacture (filtering, pressing, etc.) were much facilitated by the use of the blower. I have already pointed out the great difficulties which beset a planter who desires to make a comparative trial of a process on the ordinary lines of indigo manufacture. First and foremost is the great variation in plant and the improbability of working two or more steeping-vats under identical conditions. Again, much of the work takes place at night, and too much confidence is usually placed in natives working in the boiler and press houses. More often than not the results given out by planters are based upon cake measurement, and I have shown in a previous report (15th May, 1902) how utterly misleading such figures may be. Very often trials of a new process are carried out by planters on a comparatively small scale, and compared with the outturn of the rest of the factory. Under such conditions there is a much greater percentage of waste in filtering and pressing (which goes to form washings) than in the larger ordinary lot, and this easily accounts for a difference of 10 per cent. and upwards. Taken altogether it is not surprising that the "blowing" process (like many others) has given rise to so much controversy among planters. Because some factories obtain a substantial increase, it does not, of course, necessarily follow that all others will do the same. The liquid obtained on steeping deteriorates on standing, and one advantage of the blower is that it admits of the oxidation process being more easily carried out without delay. The blower does not create colouring matter, but by quickly getting rid of carbonic acid gas which is present in the liquid in large quantities it prevents decomposition of a portion of the colouring principle into worthless brown substances which takes place to a greater or lesser extent under other conditions. Factories, which have hitherto worked short wheel ranges and beaten off quickly, are not likely to obtain the same increase of colouring matter by adopting the blower as those having large ranges taking two and a half to three and a half hours to beat.

The blower also causes the "mal" to settle better and thereby reduces loss of indigo which invariably takes place in running off the "seet" water. Hence a greater increase is to be expected with impure water and in bad weather than under more favourable conditions by using the blower process of oxidation. Several planters informed me that they obtained an increase of 20 to 25 per cent. in

bad weather, though they were doubtful about any appreciable increase when the weather was fine. In 1901 the blower was tried with more than ordinary care on a manufacturing scale at Soogong, and on the authority of the Manager of that factory (Mr. R. R. Fenton, whose opinion I consider valuable) the process was found to be a complete success. The process gave an average increase compared with wheel-beating of upwards of 20 per cent., and the indigo realised a higher price than the ordinary Soogong indigo sold the same day in Calcutta.

Mr. MacIver found the blower process to give an increase of 30 per cent. over the ordinary at Jeetwarpore when the operation was performed in oxidising vats 3 feet 8 inches deep without pumping; but at an outwork where the vats were much deeper and the liquor had to be pumped, an increase of only 6 per cent. was obtained. Deep vats had been recommended (and 1901-1902 were largely adopted) for two reasons. In the first place, a smaller amount of perforated piping was thereby required, and secondly much less power was required for oxidation and a saving of time was effected. A vat of liquor 6 to 9 feet deep was found to be oxidised in about the same time as one of the same area containing but 2 or 3 feet of liquor. In the shallow vat much of the air escapes without producing any useful oxidising effect. In order to gain the advantage of a deep vat much of the liquor had to be pumped, and it was this operation which was afterwards found to have an injurious effect upon the process. Instead of raising the vat walls and pumping up the liquor to be oxidised it would be better to sink the floor of the beating-vat as was recommended by Mr. A. Butler. When an alkali (as in the ammonia process) is used in the oxidation vat, however, the "mal" settles quite well even after pumping.

When indigo liquor is oxidised by means of steam-blowers and air-compressors the precipitated "mal" usually contains rather more mineral matter (principally calcium carbonate) than that produced by wheel-beating. Although not by any means absolutely necessary, yet it is advisable to counteract this precipitation by the addition of a small amount of sulphuric acid to the "mal" in the boiler. The acid most commonly met with in India has a specific gravity of 1·75 and contains about 80 per cent. of real sulphuric acid. Of this acid I recommend from 4 to 5 lbs. per 1,000 cubic feet of pressed plant operated upon for air-compressors, and 5 to 6 lbs. for steam-blowers. A simple method of applying the acid is to stand a tub or

box of a capacity of about 20 gallons on two pieces of wood stretched across the top of the mal-boiler. A hole is bored in the bottom of the tub and plugged with a wooden rod reaching a little above the top of the vessel. A few buckets of water are then poured into the tub and the requisite amount of acid added. When the "mal" has been heated about half way to the boiling point, the diluted acid is allowed to run in, care being taken that it does not come into direct contact with any iron work.

Oxidising arrangements at Peeprah.—In 1901 a range of nine steeping-vats, with a total capacity of nearly 9·000 cubic feet, was placed at my disposal for experimental purposes. In connection therewith were three oxidising vats, each having an area of 400 square feet and 10 feet deep, fitted up with a No. 8 Korting's blower and the necessary piping and valves. The main air-piping attached to the blower was 6 inches in diameter. The arrangement was such that the liquor from any steeping-vat could be pumped into any of the oxidising vats, or the whole of the liquor from the nine steeping-vats could be equally divided among the three.

With a steam pressure of not less than 50 lbs. the liquor from 3,000 cubic feet of vat-room was oxidised in about 35 minutes. During the operation the temperature of the vat rose about 9 degrees F. If the pressure in the steam-boiler went below 50 lbs., the operation took much longer and the temperature rose higher. In other words, when the pressure was below 50 lbs. a much smaller volume of air was drawn through the apparatus in proportion to the steam consumed. In 1902 a fourth oxidising vat was added by which means four distinct ranges could be worked (two steeping-vats to each oxidising vat) without pumping, the liquor being at a depth of about 4 feet 8 inches. A large air-compressor was fitted up for the rest of the factory, and although two wheel-beating ranges were retained, a number of deep oxidising vats (with perforated piping) were built, capable of dealing with the liquor from the whole of the steeping vats. This installation was the property of the proprietors of Peeprah Concern though I occasionally had the use of it for experimental purposes. During the 1902 season several planters wished me to make some trials with the blower against wheel-beating, but as I pointed out in a letter to the General Secretary there were no means of carrying this out in anything like a satisfactory manner. When the plant was erected at Peeprah the desirability of a further comparison of the two processes was never

contemplated, and moreover, I was particularly requested by the Committee not to devote any more time to the matter. There is ample proof that the blowing process of oxidation is superior to that of wheel-beating, but, like most other matters connected with indigo, the variations at different factories and under varying conditions are so great that it is impossible to assign an exact value applicable to all. Some planters considered that it was merely necessary to see what amount of indigo was obtained in the wheel range at Peeprah worked in the ordinary way of manufacture and compare it with that given by the blower; but from what I have already written on the subject it must be seen that such a comparison could fulfil no useful purpose.

At the end of July, 1901, some laboratory tests were made of the oxidised liquor obtained from wheel-beating and oxidised by compressor respectively at Peeprah. On one day the results came out the same, but on the other days (four) there was an average increase of 5 per cent. in favour of the compressor. This is not much, but it is an actual increase of colouring matter formed during oxidation; increase due to more complete subsidence was not taken into account in these tests from lack of means. The compressor liquor also had the disadvantage of having been pumped.

In July, 1901, I received two samples of oxidised liquor and two samples of the corresponding seet-waters from the General Secretary for analysis. These samples had been taken from Mosheri Factory in his presence. The liquor from a number of steeping-vats had been mixed and divided between a wheel-beating range and a steam-blower oxidising vat.

The samples sent to me were merely marked No. 1 W. and No. 2 B. I submitted the following report:—

	Percentage of Indigotin.
No. 1 W.	·053
No. 2 B.	·046

"No. 1 W. contains therefore 15 per cent. more colouring matter than No. 2 B. The seet water of No. 2 B. contains more indigo than that of No. 1 W., and to such an extent that the actual 'produce' of No. 1 W. should be about 20 per cent. greater than that of No. 2 B."

I was told afterwards that No. 1 W. was taken from the "blower" oxidising vat and sample No. 2 B. from the wheel-beating range, although from the marks one might have thought the reverse. This

experiment, therefore, showed a distinct all-round gain of 20 per cent. for the blower as compared with wheel-beating.

Blower versus *compressor*.—During "morhan mahai" 1901 a question arose as to the relative value of blowers and compressor for oxidising indigo liquor. It was thought that the increase of temperature brought about by the steam-blower might be of some advantage. Accordingly arrangements were made to give the two alternative methods a trial. The liquor from a number of steeping-vats was intimately mixed and divided between two oxidising vats; one was worked with the Korting's blower as usual and the other with the factory air-compressor. Regarding the amount of colouring matter actually formed in the vat as found by anaylsis, there was very little difference. One day the advantage was with the blower; another day the results came out exactly the same, and taking the whole series of experiments (5 days) the compressor showed an increase of 3 per cent. From the indigo pressed and weighed dry, the following results were obtained:—

Average of 5 days.	Seers 60 per cent. indigo per 100 maunds of plant.
Oxidised by blower	9·53
Oxidised by compressor	10·40

In these experiments, therefore, the difference was in favour of the compressor to the extent of 9 per cent.

Deep versus *shallow vats*.—As already stated deep vats were in the first place recommended on account of general economy in working arrangements, although the original experiments at Mosheri were all made in shallow vats about 2 feet 9 inches deep. From some of the reports in 1901 it appeared at least probable that, after all, shallow vats were better, and in 1902 a number of trials were made simultaneously in deep and shallow vats. During "morhan mahai" five series of experiments were made in the following manner. The liquor from six steeping-vats was equally divided between two oxidising vats. A valve near the bottom of one leading into a third vat was then opened, and the liquor allowed to find its own level when the connecting valve was closed. In this way the

amount of liquor in the deep vat was exactly equal to the two others at half the depth. The former was 6 feet deep and the two others 3 feet each. The indigo produced in the two shallow vats was pumped into one boiler and thus made into one lot each day. In all cases the oxidation was done without the addition of any chemicals. On each day the shallow vats were found to produce more colouring matter than the deep vat to the extent of about 12 per cent., but there was evidently a greater loss in the "seet" water of the shallow vats. A summary of the results obtained is given in the following table :—

Average of 5 tests.	Seers 60 per cent. indigo per 100 maunds of plant.		
	From analysis of vat liquor.		Actual weight of indigo obtained, and weighed dry.
	Total amount produced in the vat.	Allowing for loss in seet water.	
Deep vats, 6 feet ..	9·28	6·79	6·30
Shallow vats, 3 feet	10·38	7·39	6·76
Increase per cent. by shallow vats ..	11·8	8·8	7·1

During "khoontie mahai" twelve series of experiments were made on rather different lines to those followed in "morhan mahai." The liquor from four steeping-vats was mixed and pumped into one oxidising vat. The depth was accurately measured and one-fourth run off into the next oxidising vat. The deep vat was daily of a depth of about 7 feet and the shallow vat 2 feet 4 inches. Each was oxidised without the addition of chemicals, and the results obtained are given in the following table :—

Average of 12 tests.	Seers 60 per cent. indigo per 100 maunds of plant.		
	From analysis of vat liquor.		Actual amount of indigo obtained, and weighed dry.
	Total amount produced in the vat.	Allowing for loss in seet water.	
Deep vats, 7 feet ..	12·54	11·15	10·82
Shallow vats, 2 feet 4 inches ..	13·66	11·90	9·40
Increase per cent. by shallow vats ..	8·9	6·8	Decrease.

In these experiments the shallow vats produced an actual increase of nearly 9 per cent., but after allowing for loss in "seet" water this was reduced to 6·8 per cent., figures agreeing fairly well with those obtained in the "morhan mahai" experiments. On comparing the results obtained from analysis of the vat liquors with the actual weight of pressed indigo a great difference will be observed. According to these latter figures, deep vats gave an increase of 15 per cent., but the anomaly admits of a simple explanation. I have already referred (under saltpetre in steeping) to the greater relative loss of indigo in the operations of filtering, pressing, etc., with small quantities than with larger lots. This is well exemplified in the experiments just described. During "morhan mahai" when the volume of liquor operated upon in both cases was the same, the actual weight of indigo obtained agreed fairly closely with the testing of the vat liquors. But in "khoontie mahai" the volume of liquor worked each day in deep vats was three times that of the shallow vat tests. Each day rather more than 30 seers of dry indigo were obtained from the deep vat and rather less than 10 seers from the shallow vat. In the various operations after oxidising there would be, under normal conditions, about the same loss with 10 seers of indigo as with 30 seers, but the *relative* loss in the former case would, of course, be far greater. Although only the mean results of all the experiments are given in the table, there was the same difference every day without exception. As I have previously mentioned, the results

obtained from a careful analysis of the oxidised liquor in conjunction with the "seet" water are far more reliable than those obtained from weighing the finished dry indigo. I am quite convinced that many erroneous conclusions have been drawn by planters trying a process on a comparatively small scale and comparing the returns with those given by the ordinary process worked on a very much larger scale in the rest of the factory.

At a certain meeting of the Peeprah Inspection Committee held in 1902, the Chairman expressed surprise that my report for 1901 showed a considerable increase for most of the processes tried when the actual amount of indigo resulting from all my work figured out almost exactly the same as that obtained by the ordinary process in the rest of the factory. In the first place I pointed out that there was nothing to show that the plant operated upon was of the same quality, and it was just as reasonable to compare the two department as one factory with another. The greater part of the indigo, moreover, was made by the ordinary process. With every experiment the ordinary process was tried at the same time for comparison, and for eleven days at the commencement of "mahai" the ordinary process was worked only, as the experimental "mal" boilers were not ready for use. Again, many of my experiments, as was anticipated, resulted in a loss of colouring matter. But as I stated at the time, probably the difference was chiefly due to loss in washings on account of having such a great number of small lots. We had 226 lots of indigo weighing in the aggregate 164 maunds, whereas the G. N. W. Peeprah indigo numbered only 102 lots and weighed 357 maunds. There were other possible leakages which I explained, but the Chairman still seemed somewhat sceptical and yet a few months later he made the astounding assertion that in his own factory (within a hundred miles of Peeprah) one of his ranges of vats always gave 100 per cent. more indigo than the other! Although knowing at the time there must be considerable loss with small lots, I did not realise until afterwards that it was likely to amount to such a great proportion.

I should perhaps mention that the washings from the Association indigo at Peeprah were not kept separate. On going through the Peeprah "mahai" book, I found that the washings and dust for the 10 years, 1891 to 1901 averaged 2·35 per cent. of the total good indigo. In 1901 when my experimental range was worked at Peeprah the washings and dust amounted to 4·34 per cent. of the total indigo.

It is only reasonable to assume that this extra amount (1·99 per cent.) was the result of the numerous small lots in the Association trials. The total good indigo at Peeprah (including Mudhabun and Deccaha) in 1901 amounted to 950 maunds, which at 2 per cent. gives 19 maunds as the probable weight of extra washings and dust due to the small lots. The Association indigo made in 1901 weighed 164 maunds. Calculated on this amount the 19 maunds represent a loss of 11·5 per cent. I have entered rather fully into this matter, but as many planters are so strongly convinced that weighing the indigo must of necessity give accurate results (in making trials) that I think the details will be of interest and value.

Effect of liquor standing before oxidising.—When indigo liquor is allowed to stand before being oxidised there is always a loss of colouring matter, and the indigo produced is of inferior quality to that obtained by oxidising at once. As an example of loss of colouring matter I may cite the following laboratory tests :—

	Percentage of indigotin in solution.	Percentage of loss.
14th August, 1899.		
Oxidised at once ..	·027	....
Oxidised after 8 hours ..	·0246	9·5
Oxidised after 24 hours. ..	·0225	16·6
16th September, 1899.		
Oxidised at once	·0343	....
Oxidised after 16 hours ..	·0301	12·2

When an alkaline body such as caustic soda, sodium carbonate or lime is added, and the liquor is then allowed to stand before oxidising, a still greater change takes place and the resulting indigo contains a high proportion of indirubin. The following figures are given as examples of such loss :—

	Percentage of indigotin (including indirubin) in solution.	Percentage of loss.
21st September, 1899.		
With caustic soda.		
Oxidised at once	·0211	....
Oxidised after 12 hours ..	·0170	19·4
26th September, 1899		
With lime		
Oxidised at once	·0278	....
Oxidised after 22 hours ..	·0152	45·3
11th October, 1899.		
With sodium carbonate ..	·0396	....
Oxidised after 24 hours ..	·0252	36·3

In September, 1901, experiments were made on a larger scale. The liquor from 6,000 cubic feet of vat space was equally divided between three oxidising vats; one vat was oxidised at once, the second after standing 3 hours, and the third after 6 hours. Four trials were made, and as regards colouring matter actually produced, the delay in beating caused a loss of 4 to 8 per cent., but as the "mal" did not settle (especially after standing 6 hours) as well. there was a still further loss on the indigo ultimately obtained. The following results were obtained on weighing and calculating into 60 per cent. indigo:—

Average of 4 tests.	Seers 60 per cent. indigo per 100 maunds of plant	Percentage of loss.
Oxidised at once	10·12	....
Oxidised after 3 hours	9·40	7·1
Oxidised after 6 hours	8·50	16·1

It frequently happens that when the liquor has thus been allowed to stand some time there is a decided increase of "produce" as weighed, but invariably the indigo is of an inferior quality. The indigo produced in the above trials tested as follows :—

Percentage of indigotin.		
Oxidised at once (ordinary).	Oxidised after 3 hours.	Oxidised after 6 hours.
69·6	63·6	61·8
66·6	61·2	60·6
66·6	63·0	....
69·3	63·6	62·6
68·0 average	62·8 average	61·6 average

The difference probably would have been greater but all had acid (the same amount) added to the "mal" in the boiler.

Lime to oxidising vat.—When an alkaline body such as lime, soda or ammonia is added to indigo liquor, carbonic acid (present with lime and magnesium salts in solution in large quantities) is neutralised, and calcium and magnesium carbonates are precipitated. The solution thus treated is much more readily oxidisable by air than it was before the addition, and if carried out without delay, an increased amount of indigotin is invariably obtained. Lime is much the cheapest compound for the purpose, but under ordinary conditions there are several objections to its use. In the first place lime is but slightly soluble in water and it is not easily obtainable uniform and pure in quality. On exposure to air it more or less quickly becomes partially converted into the inert and insoluble carbonate, and almost invariably contains siliceous matter insoluble in water and in acids. The most serious defect, however, for use in indigo manufacture is that it produces a much greater precipitation of earthy carbonates than do soda, ammonia, etc. The whole of the lime added, as well as a large quantity of lime and magnesia extracted from the plant, is precipitated, and unless special means are adopted the whole of this earthy matter becomes incorporated with the indigo produced. In Coventry's process, the difficulty is overcome by the use of an intermediate vat in which the precipitated earthy matters with other impurities are retained; in a process which I worked out in 1898-1899 it was proposed to get rid of the

earthy carbonates by means of acid, in definite proportions, added at a particular period of the operation.

Before discussing these methods in detail, it will perhaps be best to give the results obtained in the laboratory with lime in oxidising. Samples of liquid were taken from steeping-vats and a measured quantity oxidised by means of a small blower with and without the addition of the requisite amount of lime. The following table shows the results of four such experiments :—

	Percentage of indigotin in solution.		Increase per cent. with lime.
	Oxidised direct (no addition).	Oxidised with addition of lime.	
(a)	.. ·0253	·0308	21·7
(b)	.. ·0216	·0257	19·0
(c)	.. ·0282	·0322	14·2
(d)	.. ·0222	·0222	18·0
	Average increase per cent. ..		18·2

On the 6th October, 1899, I applied for leave to file a specification for the use of a definite quantity of alkali followed by a definite amount of acid, added in a particular manner, but a patent was not granted. The method of application of the acid was certainly novel, but I was unable to ascertain for what reason the privilege was not granted, although afterwards I heard that outside pressure had been brought to bear on the case.

The best results are obtained by adding the alkaline body (lime soda, etc.) in such proportions that a drop of the liquor, after perfect admixture, turns phenol-phthalein test paper faintly pink. This is an indication that all the carbonic acid, free and as bicarbonate, has been neutralised. On an average about 10 seers of quicklime are required for every 100 maunds of plant. The oxidation should be proceeded with at once, and this can best be done by means of the blower. When complete the requisite amount of sulphuric acid is run into the vat (being distributed by means of a perforated wooden frame) whilst the blower is still in operation,

and the blowing continued for about ten minutes. For every seer of quicklime used $1\frac{3}{4}$ seers of concentrated sulphuric acid are required. Working in this manner the full benefits to be derived from the alkaline body are obtained and the indigo produced is free from contamination with precipitated mineral matter. The object of adding acid to the beating vat was entirely to enable one to make use of the cheapest available "chemicals" for the purpose, *viz.*, lime and sulphuric acid. When sulphuric acid dissolves lime and carbonate of lime it forms sulphate of lime, and as this compound is a very sparingly soluble salt the action can only take place effectively in dilute solutions. If the concentrated "mal" containing a large amount of carbonate of lime were treated with sulphuric acid in the boiler, the indigo would be contaminated with sulphate of lime and probably also with undecomposed carbonate of lime. Hydrochloric acid could be used with effect as the resulting compound (calcium chloride) is very soluble in water, but this acid is too expensive in India for the purpose. Other alkalies such as caustic soda, ammonia, etc., added to the indigo liquor, also precipitate carbonate of lime, but not in such quantities but that it can be rendered soluble in the "mal" boiler by means of sulphuric acid.

In 1899 seven series of experiments were made at Mosheri in 1,000 cubic feet vats. On each day the liquor from two steeping-vats was equally divided between two oxidising vats. In one, the liquor was beaten by men without any addition; and in the other a steam-blower was used in conjunction with lime followed by sulphuric acid as mentioned above. The average results obtained are given in the following table :—

Average of 7 tests.	Seers 60 per cent. indigo per 100 maunds of plant. Total amount produced in the vat.	Actual amount of indigo obtained and weighed dry.
Oxidised by hand	10·87	8·05
Oxidised by blower, with lime ..	13·31	10·70
Increase per cent. by lime process	22·4	32·3

Reference has already been made (under lime and alkalies in steeping) to a patent No. 213 of 1899 taken out in the name of Messrs. Ernsthaussen, Limited. In a circular, dated 18th June, 1901, sent out to indigo planters, Mr. E. C. Schrottky claims the right to this patent and describes it as one giving exclusive privilege for the joint use of alkalies and acids in the manufacture of indigo. He has stated elsewhere that the "merits of the process have been publicly testified by Mr. Rawson inasmuch as he had applied for a patent for an identical process on the 6th October, 1899, which was not granted as exclusive privilege, for such a process had already been given." It is quite true that I look with favour upon the joint use of alkalies and acids in indigo manufacture, if applied in a proper manner and in suitable proportions, but I certainly do not approve of the process as described in specification No. 213 of 1899. The so-called "peculiar" mixture of alkalies, nitrate of soda and sugar, is a combination which I most decidedly should not recommend. In my opinion, if the process of manufacture were carried out in exact accordance with the description given in the specification, the indigo produced would be of very inferior quality and unfit for the market. The indigo manufactured at Dholi and Rajkund in 1901 bear testimony to this opinion. It is stated in the specification just alluded to that a "dextrose form of indoxyl" is precipitated with the fecula, and that this is afterwards split up by acid into glucose and indigotin. There is no evidence whatever of anything of the kind taking place. If the liquid after beating contained any undecomposed glucoside (which is extremely doubtful) it certainly would not be in the precipitate. In my application of the 6th October, 1899, I did not for a moment think of claiming novelty for the joint use of alkalies and acid, *as they had already been used for many years.* I claimed the use of acid (after the addition of alkali) in a particular manner and at a particular period of the operation. In July, 1898, I visited Belsund and was told that alkalies and acids had been used some time previously at that factory. A great number of acid jars were still on the premises. In 1897 T. S. Hill was granted a patent for the combined use of zincate of soda (an alkaline compound) and sulphuric acid. In a pamphlet, dated August, 1899, Mr. Schrottky stated that he had worked Pastau's process for 4 years. Pastau's process is merely a modification of the process described in Ernsthaussen's specification.

Perhaps the most conclusive proof, however, that the use of acid

in conjunction with alkaline bodies was common property prior to Ernsthaussen's patent of 1899 lies in the fact that in 1897 Coventry's lime and acid process was worked in many Behar factories. The acid is added to the "mal" in the boiler and its sole action (as in all cases where alkalies have been used) is to dissolve carbonate of lime which otherwise would be present in the finished indigo.

In several reports to the Association and in letters to planters (before Messrs. Ernsthaussen's application) I advocated the addition of sulphuric acid to the "mal" boiler in order to dissolve carbonate of lime normally present in indigo. The recommendation was adopted at many factories. Even if alkalies and acids had not been conjointly used before Messrs. Ernsthaussen's patent was granted, it would be absurd to contend that planters could not, on account of that patent, continue to use acid in their "mal" boilers simply because they wished to make use also of caustic soda or ammonia in beating. Moreover, in Ernsthaussen's specification it is distinctly stated that acid is added to the fecula *before it is transferred to the "mal" boiler.* No objection can be raised to Messrs. Ernsthaussen's claiming exclusive privilege for the use of the "peculiar" mixture, nor for the particular manner in which they apply the mineral or vegetable acid.

Coventry's lime and acid process.—This process has been used to a considerable extent in Behar, and its principle is well known. Briefly, the invention consists of a vat or tank placed intermediate to the steeping and beating vats into which "chemicals" of any description may be placed. The precipitate which forms is allowed to settle and the clear supernatant liquid only allowed to run into the beating vat. Exclusive privilege was granted for the process (spec. No. 61) in 1894. Lime is almost exclusively used for the operation and it answers the purpose well. As previously mentioned, lime added to indigo liquor forms a bulky precipitate of calcium and magnesium carbonates, and on settling, carries down with it various impurities which may be present in suspension. On running off the supernatant liquid into the beating-vat some of the precipitate is liable to be carried over, and unless precautions were subsequently taken to counteract this, the indigo produced would be more or less contaminated with lime. On this account, a certain amount of acid (hydrochloric or sulphuric) is added to the "mal" in the boiler. The requisite quantity of acid to use may be determined by means of blue litmus paper.

Indigo made by this process is of very superior quality and if carried out in a proper manner a substantial increased yield of colouring matter is obtained.

The only time that I had an opportunity of making trials with the process on a large scale was in September, 1898, at Dulsing Sarai, when on account of heavy rain and floods, the conditions were very unfavourable for carrying out experiments. In my first annual report, I made the following remarks on the process :—

> The principle of the process is undoubtedly sound and the indigo obtained is of excellent quality. An objectionable feature about it as now carried out is that the amount of indirubin (always above that present in ordinary indigo) obtained is a variable quantity, and it is important that dyers should be supplied with indigo of a regular composition and quality. I believe, however, by further research that this difficulty of irregularity could be overcome.

In 1901 Coventry filed a specification (No. 128) for an improvement on his original process. The chief modification consisted in continuing the pipe from the steeping-vat to the precipitator with a small connecting pipe for the introduction of lime. In this way loss of indigo by premature oxidation was avoided. I have previously shown that when indigo liquor is mixed with lime and allowed to stand for some time, considerable loss of colouring matter takes place. At the same time the relative amount of indirubin increases. It is important, therefore, after mixing that the supernatant liquid should be run off and oxidised as soon as ever possible. Whilst in the precipitating vat the liquor should be exposed as little as possible to air. The deeper the vat so much the better, and it would also be an improvement to have it completely covered in, or the air might be excluded by a thin layer of kerosine oil. On a small scale I have obtained superior results by using a little ferrous sulphate (copperas) with the lime in precipitating, and this addition I can recommend.

Coventry's improved lime and acid process, carried out with the precautions mentioned above, is well worthy of more general adoption, providing the necessary vat alterations can be made at a reasonable cost.

In a report dated the 11th August, 1902, I drew attention to a form of apparatus (Bell's patent pressure settling chamber and filter) which I considered eminently suitable for producing indigo of high quality

direct from the steeping-vat at a nominal cost. Unfortunately, there was much delay in sending off the apparatus, and it did not arrive until near the end of the manufacturing season. It was only possible to make a few experiments, but I came to the conclusion that taking the cost of the apparatus into consideration it offered no special advantages over Coventry's improved process.

Caustic soda to oxidising vat.—Caustic soda added to indigo liquor immediately before oxidising, like lime, causes the production of an increased amount of colouring matter, and by its use the "mal" settles much more completely than without the addition. It produces a much smaller amount of earthy carbonates than lime, and consequently less acid is required in boiling the "mal." Caustic soda is also free from insoluble matter which is usually present in commercial lime. The following table shows a few results obtained in laboratory experiments with caustic soda :—

Percentage of indigotin in solution.			Increase per cent. with caustic soda.
Oxidised direct (no addition).		Oxidised with addition of caustic soda.	
(*a*)	·0321	0·361	12·4
(*b*)	·0282	·0321	14·1
(*c*)	·0247	·0308	24·8
(*d*)	·0168	·0211	25·6
(*e*)	·0222	·0278	25·2
Average increase per cent.			20·4

Numerous experiments were made in small vats at Mosheri in 1899 and 1900 with caustic soda. The results varied widely but as a rule an increase of 15 to 20 per cent. was obtained in the vat itself, and after settling, an average of 30 to 35 per cent. In 1900 the process was given a very thorough trial at Peeprah both in "morhan" and "khoontie mahai." Caustic soda was used in various proportions, and for good average plant about 25 lbs. per 1,000 cubic feet of vat-room are to be recommended. The richer the plant the more caustic soda should be used, up to about 30 lbs. per 1,000 cubic feet. For very

poor Zerat plant about 15 lbs. per 1,000 cubic feet is a sufficient quantity For every pound of caustic soda used in the oxidising vat about half a pound of sulphuric acid should be added to the "mal" in the boilers. Eleven trials were made in "morhan mahai," and although the results varied greatly the average increase was very nearly the same as the average of ten tests made in "khoontie mahai." When the requisite amount of caustic soda is added to the oxidising vat, the produce from the same quality of plant is remarkably uniform, whereas that from the ordinary process shows a greater or lesser daily variation. Hence the *percentage* of increase is subject also to a great variation although the actual amount of indigo produced by the process under trial remains constant. In comparing figures, it should also be remembered that when the ordinary "produce" is very low (as with Zerat plant) the same actual gain of indigo works out to a much higher percentage than when it is high.

The following table shows the average results of 11 days' working with caustic soda in "morhan mahai." The liquor worked on each day was obtained from several steeping-vats and equally divided between the oxidising vats so as to avoid any possible error arising from irregularity of plant or of steeping :—

Average of 11 tests (morhan mahai).	Seers 60 per cent. indigo per 100 maunds of plant. From actual amount of indigo, weighed dry.	Increase per cent. by use of caustic soda.
Blower only in oxidising ..	7·48	....
Oxidised with caustic soda ..	10·83	44·8

In "khoontie mahai" samples of the oxidised "mal" were tested for indigo *produced* on each day, and these figures are given in the next table as well as the results obtained by weighing the dry indigo. The results show that caustic soda causes the "mal" to settle much more completely than it does under ordinary conditions and thus prevents loss of colouring matter in addition to the extra amount which is actually produced in oxidising :—

Average of 10 tests (khoontie mahai).	Seers 60 per cent. indigo per 100 maunds of plant.	
	Total amount produced in the vat.	Actual amount of indigo, weighed dry.
Blower only in oxidising	11·50	7·60
Oxidised with caustic soda	13·28	10·80
Increase per cent. by caustic soda	15·5	42·1

The quality of the indigo produced with caustic soda and sulphuric acid used in the proportions above mentioned was similar to that made by the ordinary process.

Sodium peroxide to oxidising vat.—G. S. A. Ranking was granted exclusive privilege in 1894 for the use of sodium peroxide, either alone or in conjunction with an acid, for oxidising indigo liquor. Sodium peroxide readily converts indoxyl into indigotin, becoming itself reduced to caustic soda. As with most other processes, planters who have tried peroxide of sodium have furnished very varying reports. In my own experiments it has certainly given an increase over the ordinary process, but it has not given such good results as the cheaper and more easily applied compound, caustic soda. Sodium peroxide is a somewhat dangerous substance to handle, and it is not, by any means, a simple matter to apply it on a manufacturing scale to the best possible advantage. Unless very great care is taken peroxide destroys a portion of the colouring matter. As a rule, I found very little increase of colouring matter on testing the oxidised liquor, and the increase ultimately obtained was principally caused by the better settling of the "mal." The most satisfactory results with sodium peroxide were obtained during "khoontie mahai" of 1901 at Peeprah, and these are given in the following table. On each day 2,000 cubic feet of pressed plant were treated, and 14 lbs of peroxide were added to the liquor:—

Average of 3 tests.	Seers 60 per cent. indigo per 100 maunds of plant. From actual amount of indigo, weighed dry.	Increase per cent. by use of sodium peroxide.
Blower only in oxidising ..	7·38	..
Oxidised with sodium peroxide ..	9·85	33·4

The quality of indigo produced by sodium peroxide was quite equal to that made by the ordinary process.

Sodium carbonate to oxidising vat.—Sodium carbonate is a milder alkali than caustic soda. Its action in the oxidising vat is rather erratic. Sometimes it has given very good results, but on the whole it is not nearly so useful or reliable as caustic soda. A small proportion produces little effect, and an excess causes some of the indigo to remain in solution. Several trials were made both at Mosheri and Peeprah, but those made in large vats in 1902 (which were under the best conditions) need only be recorded, and are given in the following table :—

Average of 4 tests.	Seers 60 per cent. indigo per 100 maunds of plant.		
	From analysis of vat liquor.		Actual amount of indigo obtained and weighed dry.
	Total amount produced in the vat.	Allowing for loss in seet water.	
Blower only in oxidising	13·80	11·70	10·88
Oxidised with sodium carbonate	15·20	13·66	12·56
Increase per cent. by sodium carbonate	10·1	16·8	15·4

Silicate of soda to oxidising vat.—R. H. Cave obtained protection (patent No. 302) in 1895 for the use of silicate of soda in the beating process, and afterwards the specification was amended so as to include the use of alkalies and alkaline earths in conjunction with silicate of soda. In 1899 Cave made a further addition (spec. No. 301) to his original patent by using hydrochloric acid. It was not recommended to add the acid to the "mal" in the boiler but to the fecula as it ran from the boiler to the straining table.

Silicate of soda added to the beating vat, like any other alkaline compound, undoubtedly produces an increased yield of colouring matter; it acts in precisely the same manner as caustic soda, but the indigo obtained from its use is much more likely to be contaminated with mineral matter. Numerous samples of "silicate of soda" indigo, which I have tested, have contained a high percentage of mineral matter and a comparatively low proportion of indigotin The use of acid in conjunction with this process, especially applied in the manner directed in the specification, is a doubtful improvement. Silicate and carbonate of lime (both of which are present in the "mal" when this process is used) are not readily dissolved, and moreover, a portion at least of the silicic acid formed by the action of hydrochloric acid on a silicate is precipitated and remains in the finished indigo.

Three series of experiments were made with silicate of soda in large vats at Mosheri in 1899 with the following results:—

Average of 3 tests.	Seers of 60 per cent. indigo per 100 maunds of plant. From actual amount of indigo obtained, weighed dry.	Increase per cent. by use of silicate of soda.
Ordinary process	9·82	..
Oxidised with silicate of soda ..	12·40	26·2

Ammonia and ammonium salts in oxidising. — In 1876 P. P. F. Michea filed a specification for the production of indigo in alkaline solutions and particularly mentioned ammonia liquor as the most suitable form of alkali for the purpose. According to the richness of the plant, ammonia was added in varying proportions up to as

much as 250 lbs. liquor ammonia (specific gravity ·891) per 1,000 cubic feet of pressed plant. A considerable amount of indigo was made by this process particularly at Belsund factory. The process was in the hands of a company known as "The Indigo Co., Ltd." The indigo produced had a very fine blue appearance (resembling Java) but it was found on analysis and by actual use in the dye-house to be of inferior quality. It contained a large proportion of mineral matter, principally carbonate of lime. Enormous yields were obtained but to a great extent at the expense of quality, although a real increase of colouring matter must have been produced. Liquid ammonia, on account of its great volatility, is difficult to handle in a climate like that of India, and moreover, it is an expensive article. For these reasons C. J. Geneste proposed to use a mixture of caustic soda and ammonium sulphate in place of liquid ammonia and obtained exclusive privilege for their use in 1889.

This mixture, although capable of producing ammonia, does not act in weak solutions (as obtained in indigo manufacture) in the same way as the free alkali, and moreover, the large amount of alkaline salts introduced into the liquor has an injurious effect upon the product. A number of trials made with a mixture of ammonium sulphate and caustic soda in large vats at Peeprah in 1901 resulted in practically the same average increase of colouring matter as with caustic soda alone.

The ammonia gas process in oxidising.—Ammonia is a most excellent compound to use in the oxidising process. It produces a direct increase of colouring matter in the vat; it causes the "mal" to settle exceedingly well; and it forms a smaller amount of lime precipitate than any other alkaline body. Ammonia liquor as such is far too costly and, as already stated, the mixture of ammonium sulphate and caustic soda proposed by Geneste cannot be recommended. For these reasons I introduced the "Ammonia Gas Process" for which I obtained exclusive privilege (spec. No. 418 of 1901) in February 1902. Gaseous ammonia finds special application when steam blowers or air compressors are used for oxidising indigo liquor, though it may be applied with advantage by an arrangement of perforated pipes at the bottom of the vat, to any form of beating. The ammonia gas may be made by any of the known processes, but for the sake of simplicity and cheapness it is preferable to use a still of such a capacity as to contain sufficient chemicals (ammonium sulphate and lime) for one oxidising operation. The still consists

merely of a rectangular or cylindrical iron vessel with three openings at the top, and a pipe with cock at the bottom for running off the waste products. It is also advisable to provide the vessel with a man-hole near the bottom in case the outlet pipe should become clogged, and for repairs. Into one of the openings at the top a pipe, reaching within six or eight inches of the bottom of the still, is fixed. At the upper end of such pipe a funnel (with cock) is attached for the introduction of the chemicals. The second opening serves for the introduction of a steam pipe which reaches to the bottom of the vessel and terminates in a traverse perforated pipe T or H shaped. A wide pipe is fixed into the third opening. It passes only just through the head of the still and is used to carry the ammonia gas into the indigo liquor. If a steam blower is used for oxidising, this outlet pipe conveying the ammonia is merely inserted loosely into the air-inlet pipe of the blower. While the blower is in action (and ammonia is being produced) the suction is so great that no trace of the gas escapes. Should the oxidation not be done by steam blowers, the ammonia outlet pipe must be securely coupled up with the vat piping and provided with a valve near the still.

Size of still.—The size of still required depends upon the volume of liquor to be oxidised. It is much better to have a still considerably larger than that absolutely necessary than one too small. In round numbers the capacity of the still should be from 25 to 30 cubic feet per pucca vat of pressed plant.

Although exact figures need not be insisted upon, the following dimensions for the liquor obtained from one, two and three pucca vats, respectively, are recommended :—

Vat space.	Still.		Steam pipe dia.	Funnel pipe dia.	Ammonia exit pipe dia.	Discharge pipe dia.
	Length.	Diameter.				
2,000 cubic ft.	6 feet	2 feet 6″	¾″	1½″	2″	2″
4,000 ,,	6 feet	2 feet 6″	1″	2″	3″	2″
6,000 ,,	6 feet	4 feet 0″	1¼″	2″	3½″	2″

In order to minimize the risk of "priming" it is advisable to attach the ammonia exit pipe to a small dome instead of fixing it direct to the top of the still. A piece of wide piping (about a foot

long and 6 inches or more in diameter) would answer the same purpose.

Amount of chemicals.—Indigo plant varies so much in potential colouring matter that it is impossible to give any hard and fast rules (from an economical point of view) regarding the amount of chemicals to be used in the process. Other things being equal, however, the richer the plant the greater the amount of chemicals required.

For good average Zillah plant, 40 lbs. of ammonium sulphate with an equal weight of lime per 1,000 cubic feet of vat-room are recommended, whilst for average Zerat plant from 25 to 30 lbs. of each ingredient are considered sufficient. Towards the end of the manufacturing season it frequently happens that the plant loses leaf and yields but a small amount of colouring matter. Such being the case the chemicals should be reduced in quantity. Not that an excess of ammonia gas would do any harm; the reduction is merely recommended on account of probable unnecessary expense.

For every 5 lbs. of ammonium sulphate used in the still, 1 lb. of sulphuric acid suitably diluted with water should be added to the "mal" in the boiler. Supposing, for example, that the liquor from two pucca vats (4,000 cubic feet) has been treated with 160 lbs. of ammonium sulphate and 160 lbs. of lime, and that the "mal" obtained therefrom has been pumped into a boiler, it will be necessary to add 32 lbs. of sulphuric acid. It will be observed that this is only about half the amount of acid required for the caustic soda treatment and indeed is little more than that which I recommended to be used many years ago for indigo made by the ordinary process.

In this process sulphuric acid is not, by any means, absolutely necessary for the production of marketable indigo as it is in the case of lime, caustic soda or carbonate of soda, but the addition of acid is recommended to produce a superior quality of indigo.

Application of ammonia gas.—In all cases the total amount of liquor in the still (ammonium sulphate solution and milk of lime) should not exceed half the capacity of the vessel.

(*a*) *Steam blowers.*—The lime is weighed out and mixed with water in the proportion of about 2 lbs. to the gallon. The milk of lime thus formed is poured into the still and heated to the boiling point. The valve of the blower is then opened and at the same time the ammonium sulphate previously dissolved in water (4 lbs. to the

gallon), run into the still whilst steam is freely admitted all the time. The cock of the funnel is closed, and when the liquid has again reached the boiling point the steam is half (or more) turned off. If all the ammonia has been evolved before the oxidation is complete this part of the operation may be stopped. In order to ascertain if all the ammonia has been given off, a small cock may be inserted on the head of the still or in the outlet pipe. On opening this cock and applying test paper or by the smell, the presence of ammonia may be readily perceived. Ammonia turns red litmus paper blue and white phenol-phthalein paper pink. The paper should only be held in the steam issuing from the cock. If it touched the cock a trace of lime thereon would produce the same effect as ammonia.

(*b*) *Air compressor.*—Before commencing operations the valve on main air-pipe (between junction of ammonia pipe and air receiver) should be closed. The milk of lime and ammonium sulphate solution (prepared as in (*a*)) should be mixed in the still cold. The funnel valve is then closed and the mixture heated to the boiling point. The air-compressor is started and immediately afterwards the main valve opened, a gentle current of steam being kept up all the time. There must be a safety-valve between the air-compressor and the shut-off valve on the main air-pipe. At the conclusion of the operation this shut-off valve must be closed immediately before the compressor is stopped. In case all the ammonia has been evolved before the oxidation is complete the steam valve on the still should be closed and immediately afterwards the valve on the ammonia exit-pipe shut. At the same time the cocks on the funnel pipe and discharge pipe should be opened.

(*c*) *Wheel-beating.*—The still should be placed near the wheel and the ammonia exit-pipe continued (of the same diameter) down the side of the beating vat across the bottom in front of the wheel, the end of the pipe to be plugged. The pipe lying at the bottom and transversely to the beating vat to be perforated with a number of ¼ inch holes, the total area of which should be rather greater than that of a section of the pipe itself. For example, a range of 6,000 cubic feet would require a still with the ammonia exit-pipe 3½ inches diameter and the portion of the pipe lying at the bottom of the vat should be provided with 250 perforations ¼ inch diameter. In commencing the operation, milk of lime and ammonium sulphate solution are added to the still as in (*b*), and the mixture heated to the boiling point. At this stage (or a little before) the wheel is started

and the passage of steam in the still somewhat reduced. The method of working the ammonia still in conjunction with the wheel is similar to that followed in the case of the air-compressor.

Results.—The first experiments in large vats with the ammonia gas process were made during "khoontie mahai" of 1901 at Peeprah, when the following results were obtained :—

Average of 3 tests.	Seers 60 per cent. indigo per 100 maunds of plant.	
	Total amount produced in the vat.	Actual amount of indigo obtained and weighed dry.
Ordinary process	9·10	5·82
Ammonia gas process	12·27	9·54
Increase per cent. by ammonia gas	34·8	63·8

In 1902 fifteen direct trials were made with ammonia gas (12 in "morhan" and 3 in "khoontie mahai") and the mean results are recorded in the following table :—

Average of 15 tests.	Seers 60 per cent. indigo per 100 maunds of plant.		
	From analysis of oxidised liquor.		Actual amount obtained and weighed dry.
	Total amount produced in the vat.	Allowing for loss in seet water.	
Ordinary process ..	9·45	6·80	6·20
Ammonia gas process ..	11·73	10·45	9·57
Increase per cent. by ammonia gas	24·1	53·7	54·3

On four days in July the weather was very unfavourable for the ordinary process and an unusually large amount of indigo ran away in the seet-water. The vats with ammonia were not appreciably affected and consequently the process on these days showed a wonderful increase (more than 200 per cent.).

Although such days are not altogether uncommon during a manufacturing season, it will perhaps be well to tabulate the results, excluding those four days :—

Average of 11 tests (4 bad days excluded).	Seers 60 per cent. indigo per 100 maunds of plant.		
	From analysis of oxidised liquor.		Actual amount obtained and weighed dry.
	Total amount produced in the vat.	Allowing for loss in seet water.	
Ordinary process ..	10·18	8·00	7·42
Ammonia gas process ..	12·22	10·90	10·17
Increase per cent. by ammonia process ..	20·0	36·2	37·0

During "khoontie mahai" of the same year "ammonia gas" was used daily in the Peeprah Factory Compressor range; one vat was oxidised by compressor only and one in conjunction with ammonia gas. The following results were obtained :—

Average of 18 days.	Seers 60 per cent. indigo per 100 maunds of plant. From actual amount obtained and weighed dry.	Increase per cent. by ammonia gas.
Ordinary process (compressor)	8·35	....
Ammonia gas process (compressor)	10·20	22·2

This increase, although a substantial one, is considerably less than that which was obtained in the experimental range of vats. Without having any desire to depreciate the value of the tests it is only right to state that it was impossible to carry out these trials in the same careful manner as was done in the vats, boilers, straining table, etc., which were arranged specially for experimental purposes. It should also be noted that these trials were made with a compressor which itself was found to give better results, to the extent of 9 per cent. than the blower used in the experimental range.

Combining the whole of the 1902 Peeprah experiments (Factory and Association), and taking actual weighings only into consideration, the ammonia gas process gave an average increase of 34 per cent. compared with the ordinary process. (The term "ordinary process" is used here although the liquor was oxidised either by a blower or compressor). In other words, every pucca vat (of 300 maunds) gave, on the average, an increase of 7½ seers of 60 per cent. indigo which represents a value of about Rs. 30. Taking the cost of "chemicals" at the outside to be Rs. 12 per vat, this leaves a clear profit of Rs. 18 per pucca vat, equal to about Rs. 26 per maund of indigo produced.

Quality of ammonia gas indigo.—Without the addition of an acid, the quality of ammonia indigo is slightly inferior on account of the precipitation of a certain amount of carbonate of lime. Sulphuric acid, however, readily removes the lime, and by its use in conjunction with ammonia it is possible to obtain much finer indigo than that given by the ordinary process. By regulating the amount of acid the quality may be kept equal to the ordinary at the particular factory where worked. At factories noted for bad colour there is no question but that the ammonia gas process would bring about a great improvement.

Referring to the experiments made at Peeprah it is noteworthy to observe that on all those occasions when the ordinary indigo was of very low quality that made by ammonia gas was of normal good quality. For example, on the first day of "khoontie mahai" (Association vats) the ordinary indigo tested 54·3 per cent. whilst the "ammonia" tested 71·8 per cent. The first day "khoontie mahai" factory vats, ordinary, tested 53 per cent. against "ammonia" 62·6 per cent.

On July 11th (Association vats) the ordinary "mal" settled very badly whilst that treated with ammonia (part of the same liquid)

settled well. The ordinary indigo on the dry tested but 49·2 per cent. whilst the ammonia indigo tested 68 per cent. On the following day the results were similar. Very little ordinary indigo was obtained and it tested but 46·2 per cent.; five times as much indigo was obtained by ammonia, and it tested on the dry 66 per cent.

Loss of indigo in "seet" water.—From several tables of results above given it will be seen that there is a great difference (especially in the case of indigo made by the ordinary process) between the amount of indigo produced in the oxidising vat and that which is ultimately obtained for sale. A portion of this loss is accounted for in straining and pressing, but the bulk of this amount is recovered as "washings." The chief loss, however, occurs in running off the seet-water, which liquid frequently contains as much as 20 per cent. of the total amount of colouring matter produced. Experiments were made with a small filter-press with a view of recovering indigo lost in this way. Although for some hours the press worked successfully, after a time the slimy nature of the deposit gradually retarded progress until the flow of liquid practically ceased. The press worked by a steam pump under pressure was found to be unsuitable for the purpose, but I fully believe it would well repay planters to go further into this question. The apparatus I should recommend for trial is known as Dehne's "Excelsior Filter." Filtration takes place under natural pressure without a pump, and the arrangement is specially adapted for filtering substances of a slimy character. A filter of this description, capable of dealing with the liquor from 8,000 cubic feet of vat-room, would cost about £60. If only 10 per cent. of indigo could be recovered it would mean a saving during a "mahai" of 60 days (on the 8,000 cubic feet) of 15 to 18 maunds of indigo.

Another method of recovering the loss is to mix the seet-water in a tank with an alkali (caustic soda or sodium carbonate), allow to subside, run off the supernatant liquid and treat the precipitated indigo in the usual way. During "khoontie mahai" of 1902 the seet-water for several days was pumped into an oxidising vat and treated daily with carbonate of soda in this manner. Altogether the seet-water from 6,000 maunds of plant was treated, and 75 seers of indigo, testing 34 per cent., were obtained—equal to 42½ seers of 60 per cent. indigo. The cost of the chemicals used (sodium carbonate and sulphuric acid) was Rs. 48, which should leave a good margin for profit. Caustic soda would no doubt have given much better

results, but at the time of making the tests sodium carbonate was the only available alkali.

Boiling the "mal."—In connection with oxidising by means of blowers and compressors, I have already recommended the use of sulphuric acid in boiling, and described a simple method of applying it. Unless the indigo made under normal conditions is of exceptionally fine quality, I would recommend acid to be used in all cases whether the liquor is oxidised by wheel, hand, blower or compressor. With fair average indigo testing about 60 per cent. indigotin, 3 lbs. of acid per 1,000 cubic feet of pressed plant is a suitable amount to use. At factories where the indigo is normally of inferior quality (testing 50 per cent. or thereabouts) from 5 to 6 lbs. of acid might be used with advantage. If carefully applied as previously described the operation can be conducted with safety in iron boilers. After boiling with acid, the "mal" should be allowed to settle, the water run off, and the vessel filled up with fresh water and heated again nearly to the boiling point. Treated in this way the quality of indigo may be improved from 5 to 10 per cent. and upwards.

Drying the indigo.—The drying of indigo, as usually carried out in India, is a slow process, and many planters have suspected that a loss of colouring matter took place during the operation. From the results of numerous experiments I have found that indigo slowly dried in the usual way invariably contains a slightly higher percentage of indigotin than the same indigo rapidly dried by artificial means direct from the press-box. This, when first observed, caused some little surprise, but it admits of a simple explanation. On entering the drying-house of an indigo factory, one is struck with the thick growth of fungi, of various, kinds, to be seen on the cakes, and the great amount of ammonia in the atmosphere. Indigotin being a highly nitrogenous body, it appeared at least probable that these effects were partly due to the decomposition of that compound, but such is not the case. Some of the impurities, always present in natural indigo, undergo decomposition with evolution of ammonia, carbon dioxide, etc. The result is, that indigo slowly dried in the drying-house weighs less than it does when dried rapidly, but it contains a correspondingly high *percentage* of indigotin. The *actual amount* of indigotin remains the same.

As an example, two cakes were taken from the centre of a press; one was dried in an air-oven and the other put in the cake-house in the usual way. The former yielded 39·5 per cent. of dry matter

which contained 58·8 per cent. of indigotin. The second cake was in the drying-house from the 11th August to the 9th November and (after finally drying in the air-oven) it yielded 38·3 per cent. of dry matter containing 60·4 per cent. of indigotin. Calculated on the original wet cakes as taken from the press, the following numbers are obtained :—

1st cake .. $39{\cdot}5 \times \frac{58{\cdot}8}{100} = 23{\cdot}22$ per cent. indigotin.

2nd cake .. $38{\cdot}3 \times \frac{60{\cdot}4}{100} = 23{\cdot}13$,, ,, ,,

Many other similar cases could be cited. In place of the ordinary air-bath, cakes were also dried *in vacuo* with like results.

In 1899 several lots of refined indigo (testing upwards of 90 per cent. of indigotin) were made at Mosheri. The cakes were dried in the factory cake-house in the usual way and showed no trace of fungus.

SUMMARY.—GENERAL CONCLUSIONS.

The more important results recorded in this report and the conclusions to be drawn from them may be thus summarised :—

Cultivation.

Plant.—On the authority of Major Prain, the ordinary plant grown in Bengal for the manufacture of indigo is *Indigofera Sumatrana* and not *I. tinctoria* as was formerly considered to be the case.

The leaf contains on an average about 0·5 per cent. of colouring matter; the variations are very great, ranging from about 0·30 to about 0·75 per cent. It is very rich in nitrogen and also contains a comparatively large amount of mineral matter. The crop from an acre of land contains, at a low estimate, 38 lbs. of nitrogen and 118 lbs. of mineral matter.

Soils.—The soils of Behar are of a very varied character. Many are highly calcareous whilst others contain but a small proportion of lime. Rarely, however, is the soil really deficient in lime. All the soils which have been examined contain abundance of potash, but as a rule, very little nitrogen. Indigo frequently grows exceedingly well where the percentage of nitrogen in the soil is low. Phosphoric acid in Behar soils is a very variable quantity; in a great many cases the soil is decidedly deficient in available phosphoric acid.

Manuring.—Whenever phosphoric acid is deficient in the soil, superphosphate of lime can be applied with advantage. It is decidedly the best general manure to apply to indigo lands. Nitrogen, in the form of nitrate of potash (saltpetre) in conjunction with superphosphates, usually still further increases the production, yet on account of cost it is questionable whether the use of nitrates will generally prove remunerative.

Manures should be applied not later than September in order that they may become thoroughly incorporated with the soil during the rains.

Seet.—Refuse plant or "seet" is a very valuable manure, principally on account of the nitrogen which it contains. In comparison with the present market prices of oil-cake and ammonium sulphate in Behar, a ton of good "seet" is worth from Rs. 12-8 to Rs. 13-8. In order to grow such crops as sugar, tobacco, cereals, etc., successfully in India nitrogenous manures must be employed, and for this

purpose "seet" is eminently suitable. With the present low prices for indigo it may well happen in some factories where the outturn is below the average that the value of "seet" as a manure for other crops exceeds that of the indigo obtained from a given weight of plant.

"Seet" applied to indigo lands usually produces an excellent crop, but the leaf on such plant is invariably deficient in colouring matter. In my opinion, to apply "seet" *direct* to land for growing indigo is irrational and wasteful. Moreover indigo grown on "seeted" land is more liable to be attacked by caterpillars and other pests.

Colouring matter in plant.—The colouring principle exists almost exclusively in the leaf. As the plant grows the colouring principle gradually increases until it reaches a maximum about the end of August. On the same plant, new leaf is richer than old, and leaf near the top of a plant contains more colouring matter than that near the bottom.

Rain does not wash away any of the colouring principle from growing plant, although after heavy rain "produce" invariably falls. The diminution is due to a number of causes: (1) the plant is weighed wet and no allowance is usually made in factories on this account; (2) the "mal" after oxidation does not settle well and indigo is lost in the "seet" water; (3) the lowering of temperature which occurs causes imperfect fermentation in steeping; (4) probably rain washes away enzymes which undoubtedly play an important part in steeping.

Burnt plant is practically devoid of colouring matter and should be kept out of the vats.

Zillah and Zerat plant.—The difference in the quality of plant grown in "new" land or by the *ryot* in rotation, and that grown year after year in succession on the same land, is very great. At Peeprah, plant grown on Zerat lands only yielded from 4 to 5 seers of indigo per 100 maunds, whereas Zillah plant gave about 10 seers.

Stripping leaf.—Experiments with stripping gave some interesting results though the estimated cost (about Rs. 12 per 100 maunds) worked out to rather a high figure. With the hot-water or steaming system of extracting the colour principle, the *leaf only* would be of the greatest advantage. For the ordinary steeping process it is better to use the whole plant.

Natal plant.—This plant is much more hardy than the ordinary plant cultivated in Bengal, and the leaf contains, on an average, con-

siderably more colouring matter. Taken altogether, the experiments made with Natal plant were very promising, though more work is required to find out the best method of cultivation for Behar as well as the most suitable time of year for cutting the plant.

Polygonum tinctorium.—This plant grows in temperate climates, and its cultivation in Behar, either before or after the ordinary indigo season, is well worth consideration.

The leaf itself is not very rich in indigotin, but the whole plant contains about as much colouring matter as the ordinary indigo plant.

Manufacture.

Cutting.—About the middle of July in normal years is the best time to commence cutting the plant in Chumparun and Tirhoot. After cutting, the plant should be steeped as soon as possible.

Loading the vats.—With good average plant about 120 imperial maunds per 1,000 cubic feet vat capacity gives the best all-round results. The poorer in quality the plant, the heavier should be the loading. With poor sticky Zerat plant it is best to load to the fullest possible extent.

Steeping.—With good water and favourable weather there is little (if any) room for improvement in the steeping operation as generally carried out in well-managed factories in Behar. With bad water and unfavourable weather, the outturn is frequently very inferior both as regards quality and quantity.

Time of steeping and temperature of water.—When the water is at a temperature of 90 degrees to 92 degrees F., about 12 hours' steeping has been found to give the best results. For every 2 degrees under 90 degrees an extra half-hour should be allowed, and for every 2 degrees above 92 degrees half an hour less should be given. When the water is under 90 degrees it is preferable to raise the temperature by means of steam-pipes placed in the "kajana."

Water used in steeping.—Water which is bad for indigo manufacture invariably contains much organic matter, especially minute living forms. It may be purified and rendered quite good for the purpose by treatment with potassium permanganate and lime. From 2 to 10 oz. of permanganate per 1,000 cubic feet of water should be used, and for the same volume half a pound of good quicklime for every grain of carbonate of lime (or for every degree of hardness) present per gallon.

The best way of treating the water is in raised tanks on the Archbutt-Deeley system, but it can also be done in the "kajana" direct, though not so well.

Saltpetre in steeping.—Saltpetre does not produce an actual increase of colouring matter in the vat, but its use causes the "mal" to settle better after beating, and on this account an increased yield of indigo is usually obtained. When an alkali is used in the oxidising vat, there is no advantage to be derived from adding saltpetre to the steeping vat. Without any other "chemicals" in the process, saltpetre acts beneficially, and under those conditions its use can be recommended.

Antiseptics in steeping.—No benefit was found to be derived from the use of carbolic acid, mercuric chloride, or of permanganate of potash in steeping. Formaldehyde prevented the formation of indigo altogether.

Extraction with hot water.—When indigo plant is immersed in water at a temperature of 150 degrees to 160 degrees F., the colouring principle is quickly extracted and transformed, through the agency of enzymes, into indoxyl, which is converted into indigotin by the action of air. Indigo made in this way is always of superior quality to that manufactured by the ordinary steeping process. Its composition is regular, containing usually about 75 per cent. of indigotin.

Contrary to expectations, the accumulative system of extraction was not found to give such good results as a simple extraction in ordinary vats fitted up with perforated iron steam pipes. Except as regards quality, the hot-water system offers no advantage over ordinary steeping carried out under favourable conditions. In wet, cold weather, however, the method (compared with the ordinary process as usually followed) would well repay the cost of steam which is about Rs. 4 per 1,000 cubic feet of vat-room.

Extraction with boiling water.—Extraction by means of boiling water could only be worked advantageously on the accumulative plan, and in my opinion, the cost of such a system (using the whole plant as at present) would be altogether prohibitive.

Extraction by steaming.—This method of extraction is superior to that of using boiling water, but there are the same objections, though to a lesser degree, regarding cost of apparatus and of fuel. Further bacteriological research would no doubt enable one to ferment the resulting liquid by pure cultures of bacteria or by en-

zymes in a systematic and scientific manner. Apparatus to treat the whole plant would be far too costly, but if satisfactory arrangements could be made to bring leaf only to the factory, this method of extraction and its further treatment, as suggested, would form an ideal process of indigo manufacture.

Oxidising by blowers and compressors.—This method of oxidation is undoubtedly superior to wheel-beating. For reasons given at some length in the report it is difficult, if not impossible, to assign an exact value to the increase obtainable. In round numbers, however, both from my own experiments and from the reports given by various planters, I should put the average increase at 20 per cent. If no alkaline body is added to the oxidising vat, I should recommend the depth of liquid treated not to be greater than 4 feet. If caustic soda or ammonia is used, however, far deeper vats can be worked with advantage.

Effect of liquor standing before oxidising.—It frequently happens in indigo factories (especially where there are large ranges of vats) that the steeped liquor is run into the beating vats some hours before it is oxidised. Under such conditions there is always a loss of colouring matter, and the indigo produced is of inferior quality. A number of experiments made on the large scale showed that a loss of 7 per cent. took place in liquor standing 3 hours and as much as 16 per cent. on standing 6 hours. In the presence of an alkali a change for the worse takes place more rapidly on standing.

Lime to oxidising vat.—Lime added to the beating vat produces a distinct increase of colouring matter, and there is a still further increase due to the "mal" settling more completely. In laboratory tests an average increase of 18 per cent. was obtained in the oxidised liquor. In 1,000 cubic feet vats lime produced in the liquor an average increase of 22 per cent., and on weighing the dry indigo an increase of 32 per cent. was obtained. There are various methods of applying lime in indigo manufacture, but that used and patented by B. Coventry is unquestionably the best.* A certain amount of colouring matter is lost in the lime-mud precipitate, but it is small compared with the increase obtained. In conjunction with acid in the boiler the indigo produced is of the finest quality.

Caustic soda to oxidising vat.—Caustic soda added to indigo liquor immediately before oxidising acts in much the same manner as lime. When no intermediate vat is used it is much superior to lime inasmuch as a smaller amount of earthy carbonates are formed

and consequently less acid is required in the after-treatment of the "mal." Caustic soda is also free from insoluble silicious matter. On the large scale an increase of 43 per cent. of dry indigo (as weighed) was obtained by the use of caustic soda.

Sodium peroxide to oxidising vat.—This compound gave in large vat experiments an average increase of 33 per cent. As a rule little or no increase of colouring matter was obtained in the vat itself, and that ultimately obtained was principally caused by the better settling of the "mal." On the whole caustic soda gave much better results than sodium peroxide, though the latter has the advantage (with quantities recommended) of not requiring acid in the "mal" boiler.

Sodium carbonate to oxidising vat.—This form of alkali is not nearly so useful or reliable in the oxidising process as caustic soda.

Sodium silicate to oxidising vat.—The compound, like all other alkaline bodies, produces a decided increase of colouring matter. In sufficient quantity it acts in the same manner as caustic soda, but it has the disadvantage of forming earthy precipitates which are not easily removable, and the indigo obtained is frequently of inferior quality.

Ammonia gas in oxidising.—I consider this process offers the most perfect method of oxidising indigo liquor which can be put into the hands of planters. It has produced a greater increase of colouring matter than any other process.

Fifteen experiments on the large scale resulted in an average increase of 54 per cent. On four days out of the fifteen the weather was very bad, and this naturally showed the process to very great advantage. If the four days be excluded, however, the average increase for the other eleven days was still as much as 37 per cent. Indigo made by this process is of excellent quality, and it is not affected by bad weather. On the four bad days above mentioned the "ammonia" indigo tested 66 to 68 per cent., whereas that made in the ordinary way (which was very small in amount) tested only 46 to 50 per cent.

Loss of indigo in seet water.—A great amount of indigo is lost at every factory by running off seet-water containing more or less colouring matter in suspension. On many occasions this loss amounts to as much as 20 per cent. and upwards of the total indigo produced. It is much reduced by using an alkali in oxidising, but even then there is some loss. Experiments were made with a

view of recovering the loss by means of a filter-press but they were not successful. I would recommend, however, trials being made with an "Excelsior" filter. When the ordinary process is used a great portion of the indigo may be recovered by treating the seet water in a tank with caustic soda.

Boiling the "mal."—In this operation indigo (unless of exceptionally fine quality normally) may be much improved by the addition of sulphuric acid to the "mal."

For fair average indigo (testing about 60 per cent.) made by wheel-beating, 3 lbs. of acid per 1,000 cubic feet of pressed plant, is a suitable amount to use. With inferior indigo (testing 50 per cent. or thereabouts) from 5 to 6 lbs. of acid might be used with advantage. When air-compressors are used in oxidising, 4 to 5 lbs. of acid per 1,000 cubic feet of pressed plant should be added to the "mal" (for good average indigo) and 5 to 6 lbs. in the case of steam-blowers. When caustic soda is added to the oxidising vat, one lb. of acid is required for every 2 lbs. of the alkali; and in the ammonia gas process one pound of acid for every 5 lbs. of ammonium sulphate put into the still.

Drying the indigo.—It has been found by experiment that indigotin is not destroyed during the slow-drying process.

Some of the natural impurities undergo decomposition with evolution of ammonia, carbon dioxide, etc. The result is, that indigo slowly dried in the cake house weighs less than it does if dried rapidly, but it contains a correspondingly higher percentage of indigotin. The actual amount of indigotin remains the same. Refined indigo (free from natural impurities), dried slowly in the cake house, does not become covered with fungus like ordinary indigo.

Outline of Manufacturing Process Recommended.

In giving a brief outline of the process of manufacture to be recommended, I confine myself to improvements in the general system which is now carried out in Bengal. Other methods of extraction requiring special apparatus have been discussed in the report; their advantages and disadvantages have been pointed out, but taking all things into consideration, I cannot recommend their general adoption. A different aspect would be presented if *leaf only* could be brought to the factory at a moderate cost.

As regards cutting and loading, little need be added to the remarks made in the above summary. Instead of beginning "mahai"

gradually, I would recommend the whole of the vats to be filled from the commencement, and to be worked fully until the plant is finished. The plant should be put into the vats and watered with as little delay as possible. Of two evils, however, it is better to keep the plant standing on carts than put it into vats which cannot be immediately watered.

Impure water should always be treated with potassium permanganate and lime in the proportions already given, *viz.*, 4 to 10 oz. of permanganate per 1,000 cubic feet of water, and 8 oz. of good quicklime for every degree of hardness per 1,000 cubic feet. Whatever may be the quality of the water, lime in these proportions acts beneficially. Water treated with permanganate should not be run into the steeping-vats under an hour after admixture. At a temperature of 90 degrees to 92 degrees F., steeping for 12 hours is recommended. If under 90 degrees, the water in the "kajana" should either be heated or a longer steeping given. After heavy rain an hour's extra steeping is recommended in addition to any allowance made for temperature. When alkalies (especially ammonia) are used in oxidising, a *little* oversteeping does no harm.

Oxidising.—It is in this operation where there has been the greatest room for improvement. In case any planter should still have a prejudice against using "chemicals," I recommend either blowers or air-compressors to be used for oxidising indigo liquor (in place of the wheel) at a maximum depth of 4 feet. There can really be no possible objection, however, to the use of either ammonia or caustic soda in conjunction with sulphuric acid, nor to lime applied in accordance with Coventry's improved process.

All these three processes are good, and are capable of giving very satisfactory returns for the extra outlay involved. Of the three methods, I particularly recommend the "ammonia gas" process which is applicable to any form of beating. From a given volume of indigo liquor "ammonia gas" produces the greatest possible amount of colouring matter.

As regards quality, the indigo made by this process is at least equal to that made by the ordinary process at the best factories in Behar, and much superior to the average ordinary product.

If extreme purity of colour is the chief desideratum, then Coventry's improved lime and acid process is decidedly the best.

Caustic soda, applied in the manner described in this report, is

capable of giving excellent results though preference is given to either "ammonia gas" or to Coventry's process.

Whenever these alkaline compounds are used in oxidising, the vats for blowers and compressors may, with advantage, be deeper; but in conjunction with ammonia, caustic soda or Coventry's process, alteration of existing wheel-beating ranges is not specially recommended. Wherever wheel-beating is retained, large ranges should be made smaller so as not to exceed 6,000 cubic feet.

Boiling.—The requisite amount of sulphuric acid to be added to the "mal" in boiling for the various processes described has been already given in the summary.

Conclusions.

If planters generally adopt the recommendations which have been made in this report, I feel convinced that they will reap very material benefit. Excepting the possibilities regarding treatment of *leaf only* with hot water or by steaming as pointed out, I don't think there is still further room (to be remunerative) for materially improving the manufacturing process beyond what has been recommended in this report.

Regarding the general welfare of the industry, the value of "seet" as a manure for other crops is an important factor, as is also the application of superphosphate of lime to indigo lands deficient in available phosphoric acid.

The cultivation of indigo on land which has been known for years to give but poor returns should be abandoned. As far as possible, old Zerat lands should be devoted to growing other crops and not put into indigo again for some years. More attention should be paid generally to the selection of land most suitable for the cultivation of the plant.

Finally, any further aid (from a technical point of view) to improve the position of the indigo industry can only come, in my opinion, from improvement of the plant by natural selection or by the introduction of some other species (such as Natal Plant) capable of yielding a greater amount of colouring matter.

REPORT

OF THE

INDIGO RESEARCH STATION, SIRSIAH,

(*Under subsidy from the Government of Bengal.*)

FOR THE YEAR 1907–1908

1905 – 6

BY

CYRIL BERGTHEIL.

INTRODUCTION.

THE work to be described in this report was commenced at Pemberandah in August 1904, and has thus been in progress for eighteen months. A considerable part of this time has, however, been occupied in equipping and fitting the factory and laboratory at Sirsiah.

In a preliminary report, published in February last, I described briefly the lines of work I intended following, and to that end divided my report into two sections, the first dealing with the manufacture of indigo and the second with its cultivation. I propose pursuing the same plan in this report, and will deal first with manufacture and problems bearing thereon, since most work has hitherto been done on this aspect of the question both by my predecessors and myself.

MANUFACTURE.

Review of previous work.

It would be well, perhaps, to first briefly recapitulate what had been done in investigating the manufacture of indigo in India before the present work was undertaken. Such work was begun in 1898. Previous to that year many "processes" had been evolved and patented, but these were mostly of an ephemeral nature, and none were grounded on a thorough scientific investigation of the operations concerned.

Work of Rawson.

In 1898 Mr. Rawson began the work which was continued in Behar for five successive seasons. He has embodied his results in a report dated 1904, which is a record of quite the most complete investigation of the cultivation and manufacture of indigo ever published; every stage of the process is dealt with, from the purification of the water used in steeping to the drying of the finished indigo, and valuable suggestions are made as to how improvement may be effected in most particulars. I shall have frequent occasion to refer to this report, and shall do so under the single word "Report."

Work of Bloxam.

In 1903 Professor Popplewell Bloxam inaugurated researches on indigo at Pemberandah, Dalsing Serai. The results of this work, which extended over a little more than a year, are embodied in a rather voluminous report published in 1905. The essential matter can be condensed into a very few words. Primarily, Professor Bloxam came to the conclusion that no known method of indigo

analysis was sufficiently reliable to serve as a foundation for any investigation of its manufacture, and that it is impossible to conduct any such investigations until this is remedied. Secondarily, he is led in the course of his investigations into the analysis of indigo into an examination of the red colouring matter (or matters) of plant indigo, and concludes that it (or they) does not contain nitrogen and therefore no indirubin, which is a nitrogenous body and has always been supposed to be the main red constituent of indigo.

If Professor Bloxam's conclusion with regard to the methods of indigo analysis is correct, it follows that all Mr. Rawson's work, which was based upon his permanganate method of estimation, is valueless, and it became necessary, therefore, to decide whether this was so before undertaking further work. As a matter of fact, I had already had sufficient experience of the method in question to be convinced of its reliability within the limits necessary to the investigation of any commercial process, but in order to determine the precise degree of error liable to occur in an analysis, a systematic examination of it has been taken up and is now in progress. Incidentally other standard methods of indigo analysis are being critically investigated, and an account of the whole work will be published as soon as complete. Sufficient knowledge had already been obtained before the commencement of the manufacturing season this year to confirm the opinion that the maximum error likely to occur in analysing an indigo of average purity by the permanganate method was about 2%. This method was accordingly used throughout the investigations about to be described.

Prof. Bloxam's observations with regard to the red bodies in indigo would, if correct, be of less vital importance than those on the analytical methods. Preliminary re-examination of the point raised has shown decisively that there is more than one red body in most commercial indigos, and that at least one of them is not only nitrogenous, but that it contains very nearly the correct amount of nitrogen to correspond with indirubin. Its properties are precisely those attributed to indirubin, and it is very probable that if it can be obtained in a chemically pure state its analysis will correspond exactly with that of indirubin. This matter is also under investigation, and a paper dealing with it will be published in due course.

"Efficiency" of "Mahai."

Prof. Bloxam points out that the "efficiency" of the manufacturing process as ordinarily carried out has never been determined, and expresses the opinion that it is very low. By the term "efficiency" is implied the proportion which exists between the

amount of indigo obtainable from the plant put into the vats and the amount obtained at the end of the process. This is, of course, the primary question to be answered before any improvement in manufacture is attempted, and I had already expressed my intention of making its solution one of the main objects of my experiments in my report of February last. From a consideration of Rawson's work it is clear that he suggests various methods by which the process can be made more efficient, but his suggestions are mainly concerned with the oxidising operation, and I was convinced before taking up the present work that with the aid of his ammonia process this latter part of the manufacture was as efficient as could be desired, that is to say, that all the indigotin which can be obtained from the liquor coming out of the steeping vat is actually so obtained.

Of the steeping process as usually carried out Rawson expresses the opinion that " with good water and favourable weather there is little, if any, room for improvement " (Report, p. 33). If this is so; and the ammonia process provides a perfect method of oxidation, there can be no scope for further amelioration other than in respect of the mechanical devices used, such as presses, etc., and in ensuring pure water and the conditions characteristic of favourable weather. It was in fact Rawson's opinion that this is so (Report, p. 97).

No estimate hitherto formed with regard to the efficiency of the steeping process has been supported by figures, and it is evident that a verification can only be arrived at by knowing precisely the amount of indigo obtainable from the plant put into the vats and comparing this with the amount obtained in the oxidising vat, assuming always that the method of oxidation is perfect. This involves a reliable means of analysing the plant with regard to its capacity for yielding indigo, and a method devised by Rawson for this purpose (Report, p. 20) presumably formed the basis of his opinion of the efficiency of the manufacturing process.

In the course of an investigation into the *modus operandi* of the steeping process carried out in 1903, I had occasion to compare the amounts of indigotin obtainable from an extract of the indigo plant by this method of Rawson's, and by fermentation with indigo-enzyme and oxidation by air. It transpired that a larger quantity of indigotin was invariably obtained by the latter method (Journal of the Chemical Society, 1904, vol. 85, p. 879). This led me to suspect that Rawson's method gave too low results, and it was my

first care on taking up work at Pemberandah last year to see whether a suitable chemical method of analysis could not be devised which would give results which would fall into line with those obtained by enzyme fermentation. By a slight modification of Rawson's method this was accomplished, and this revised method has served as a basis for estimating the efficiency of the processes carried out during the past season. A description of this method will be included in the paper shortly to be published on the analysis of indigo.

The discovery of this error and its remedy seemed to encourage the idea that it would be well worth while devoting some time to an accurate determination of the efficiency of the ordinary manufacturing process, since there might after all turn out to be more room for improvement than was supposed, and in any case a numerical determination of the condition of affairs was desirable.

Influence of temperature on steeping.

In the course of the research into the fermentation of indigo above mentioned, I was led to the conclusion that no ordinary chemical substance added to the steeping vat could in any way accelerate or otherwise improve the steeping operation, and that, in fact, the conditions ordinarily holding in the vat were the best for fermentation, provided the water used is soft and pure and its temperature sufficiently high. This last is a very important point, the temperature of the water having a very profound effect upon the result obtained. The advantages of heating the water a few degrees on unusually cold days is pointed out by Rawson (Report, pp. 33, 34), and a process in which the fermentation is carried out at an elevated temperature (150-155 degrees F.) is described by him (Report, p. 48); various "hot-water processes" have been described from time to time (Report, pp. 47, 48), and it is well known that the practice in Java involves using heated water. So far, however, no systematic course of experiments has been conducted in India with a view to determining the best temperature at which to work, and the period of steeping which gives the best results at that temperature. Such a series of experiments was suggested by Rawson (Report of 1899, p. 19), but, so far as I know, was never carried out.

I was convinced at the outset of this work that if it were found that there was still room for improvement in manufacture it would be in this direction, and decided, therefore, to make this the main object of the "mahai" work whilst incidentally determining the efficiency of the ordinary process. Some knowledge of the effect

of temperature upon the fermentation process had already been gained, and it had been shown that the rate at which it proceeded increased with a rise of temperature up to 122° F., and then decreased with a further rise; at a higher temperature, however, the indigo-yielding body in the fermented liquor underwent change into another substance which was incapable of yielding indigo (Journal of the Chemical Society, 1904, vol. 85, pp. 883-886). It was doubtful, therefore, whether the beneficial effect which might be expected to arise by heating the water in the steeping-vat to a temperature which would not only accelerate fermentation, but would also exclude the possibility of harmful bacterial putrefaction, would be apparent in the result, since the change referred to in the fermented liquor would act in an antagonistic direction.

Preliminary experiments were carried out in the laboratory, but although the results obtained indicated approximately the optimum-period for steeping at each temperature, they were not directly applicable to the manufacturing process since the conditions holding when only a small quantity of plant is operated upon are so widely different from those occurring in the vats. It was necessary to arrive at a correct conclusion to test the matter on a manufacturing scale. Past experience had shown that even 100 cubic feet vats were apt to give misleading results, and it was considered that 500 cubic feet must be the smallest size employed to give reliable information.

Arrangement of experimental factories.

Accordingly, the experimental factories at Sirsiah and at Pusa were designed to each comprise a range of five 500 cubic feet steeping vats with corresponding oxidising vats fitted with steam blowers connected with an ammonia still for using Rawson's process. At each factory arrangements were made for heating the water in the reservoir before supplying it to the vats by means of perforated steam pipes, and every facility was provided for keeping two lots of indigo separate so that two processes could be compared from start to finish. The water was heated in the reservoir rather than in the "mooree" or in the vats themselves, because either of the two latter courses is apt to lead to uneven heating. Rawson's ammonia process was used for oxidising throughout the experiments, because it was essential that the only variable in the processes employed should be in the steeping vat, and the ammonia process appears to supply the only means of ensuring perfect oxidation. It may be objected that by introducing this method into the experiments the "ordinary" process as understood by planters has not been dealt with. The reply to this

is, that without so doing it would be quite impossible within a reasonable number of tests to obtain concordant results, the variation in the efficiency of oxidation being so great, but that, on the other hand, the ammonia process effects very little, if any, improvement over "ordinary" oxidising when this is carried out under optimum conditions of speed, weather, water, etc., so that results obtained with its use represent the optimum conditions of "ordinary" oxidation. The process is thus of the nature of an assurance of perfect oxidation, and it is for this reason that it has been used in the following experiments, and for this reason that I consider it should be used by every planter.

Sulphuric acid was, of course, used in boiling, but this is only of importance in considering the results obtained in connection with quality, since samples for estimating quantity of yield were withdrawn direct from the oxidising vat.

Method of Conducting and Controlling "mahai."

The method of conducting and controlling the manufacturing process was as follows:—An area of cultivation showing as even growth of plant all over as possible was selected for each day's experiments and cut, as a rule, in the early morning, though when the "ordinary" process with a long period of steeping was used it was found necessary to cut in the afternoon and load last thing in the evening. The carts were loaded as evenly as possible and carefully weighed on entering the factory, the weight of plant each carried being then determined by deducting the previously determined weight of the empty cart. The carts were then allotted to the vats in such a way as to give an equal weight of plant to each vat, and an effort made to keep each load as near 60 maunds (*i.e.*, 120 maunds per 1000 cubic feet) as possible, this being the rate of loading recommended by Rawson (Report, p. 31). The carts were weighed again on leaving the factory empty to confirm the weight used in determining each load. This is very necessary on wet or muddy days, since the weight of the cart varies a good deal under these conditions. The vats were loaded simultaneously as far as possible, and samples of plant were taken from each cart at intervals during the unloading. These were quickly carried to the laboratory and weighed, the leaf was then rapidly plucked from each sample, and the stems again weighed. In this way the percentage of leaf of the sample of plant examined was determined. This is a most important point, and great care was taken to ensure working as accurately as possible. In most cases samples representing two or three cartloads at a time had to be taken, but by taking these

quickly and from different parts of the load the samples obtained must have been very fairly representative. The leaves plucked from the plant samples were also weighed and one or more small samples taken representing each vat load for analysis. Allowance was made in calculating the results of these analyses for the loss in weight, due to evaporation of water, which the leaves underwent between first weighing the plant and taking the samples for analysis.

The water for steeping was purified if necessary by the addition of lime and permanganate (*vide* Report, p. 35) in a specially-constructed vat from which it could be pumped into the supply reservoir. Here it was heated to a temperature about 9° F. above that at which it was desired to steep, since it was found that this represented the average drop which the temperature underwent in flowing to the vat, and due to contact with the cold masonry and plant, etc.

Upright bamboo or wood frames were placed in the vats opposite the outlet of the water supply-pipe so that the water flowed directly to the bottom of the vat instead of running over the plant; the frames also served to provide a convenient place for reading the temperature of the water in the vat at intervals. The vats were covered with rough mats in order to avoid as much loss of heat as possible, and also to keep rain out.

The temperature of the vats was taken on first filling and afterwards at intervals of half an hour, and that of the water supplied so regulated as to make the average temperature during the steeping period correspond as nearly as possible with that recorded as the temperature of experiment. Four vats were, as a rule, worked each day, two experiments being done and each in duplicate.

The liquor was oxidised immediately the vats had finished running off. This is always a matter of great importance, but particularly so when working hot-water processes. The completion of oxidation was determined by filtering a small sample of the liquor, moistening a piece of white blotting paper with the filtrate and holding it over the mouth of a bottle containing strong ammonia (*vide* Rawson 1899 Report, p. 26). Immediately the test showed completion, and before the blower was turned off, a sample of the liquor was withdrawn from the vat and taken to the laboratory for analysis, and as soon as the liquid had completely settled down its depth was carefully measured and recorded. The superficial

area of each vat was previously known, so that in this way the total amount of indigotin produced in the vat was obtained.

After this the procedure was the same as that of any ordinary factory, except that in a few cases the seet water was analysed; it was found impossible, however, to do this in every case. The mahl from each pair of vats was kept separate during the boiling, straining and pressing and all subsequent processes, and the indigo produced by each experiment was analysed when dry.

A typical record of one day's experiments would thus read as shown in the opposite page.

Explanation of table.

It will be seen that such a record contains all the data necessary for the determination of the efficiency of any given process, this being derived from the relation existing between the figures in columns IX and XI. A few remarks are necessary in explanation. In the first place, it will be noticed that only the leaves of the plant are taken into consideration. This is justified by the observation of all previous workers, which has been frequently verified, that the colouring matter is derived from this part of the plant only. In the second place, all results of analyses are expressed in indigotin. This is a necessity of the case, since we have no means of estimating the other constituents of indigo, but since these other constituents are of very secondary value as compared with the indigotin (if of any value at all) the amount of this constituent produced and produceable gives all the necessary information. It should be noted that the samples analysed to give the actual yield of indigotin by any process were drawn from the oxidising vat, so that no loss at any subsequent stage of the process comes into consideration. Such losses invariably take place to a greater or less degree, but their extent is very variable, and their avoidance, though very important, is a purely mechanical consideration and does not enter into the present discussion of the chemical processes involved.

Leaf content.

In connection with the determinations of leaf content, of which some hundreds were carried out, I should like to point out that in no case of Sumatrana plant, either at Sirsiah or at Pusa, has the percentage of leaf been found higher than 45, the average being about 40. This is in accordance with Rawson's determinations, but contrary to those obtained by Professor Bloxam at Pemberandah, the average of the samples examined by him being considerably higher. I can only explain this as having probably been due to the plant examined at Pemberandah being grown under special conditions on experimental plots or from selected seed. The high percentages

AUGUST 8TH. SUMATRANA PLANT, 4 HOURS AT 122° AGAINST 12 HOURS AT 86°.

I.	II.	III.		IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	
Process.	Number of Vat.	Weight of Plant.		Average percentage of leaf.	Superficial area of Vat in square feet.	Depth of liquor in feet.	Per cent indigotin in liquor from oxidising vat.	Total indigotin produced in pounds.	Pounds of indigotin obtained per maund of leaf.	Percentage of indigotin in leaf by analysis.	Pounds of indigotin obtainable per maund of leaf.	Efficiency of process.	Percentage of total indigotin produced lost in seet water.	Cake Number.	Percentage of indigotin in finished indigo.
		Maunds	Seers.												
4 hours at	I.	64	10	36·7	139·05	2·57	·036	7·98	·338	·574	·473	71·5%	7·8	23	69·2
122° F.	II.	62	20	40·9	139·05	2·58	·03	6·75	·264	·458	·377	70%	9·5		
12 hours at	III.	57	10	38·2	139·05	2·47	·028	6·03	·275	·524	·432	63·7%	..	21	62·8
86° F.	IV.	57	28	40·1	138·8	2·28	·033	6·6	·284	·529	·436	65·4%	..		

found by Professor Bloxam are certainly not characteristic of Sumatrana plant grown under ordinary agricultural conditions.

Method of expressing Results.

The results of the two "mahais" carried out involve a great many figures, and would be too voluminous to record in detail. I have summarised them in the following table by taking averages of the figures expressing the efficiencies of each experiment carried out and the qualities of the indigos obtained. Most of the figures represent an average of four or more tests since no two days' processes were compared with one another, but each process compared with every other until an optimum period of steeping for each temperature was arrived at. Thus if 7 hours at 104° was found to give a higher efficiency than 8 hours at the same temperature, it was tried again against a 6 hours' steeping next day, and unless the 7-hour steeping again gave the best result (which would declare it the optimum period for the temperature) the 6 hours would be tried again against 5 hours on the third day. This course was necessary, since the quality of plant used on different days was so very varied. In this way nearly every process was tried on at least two days with each of the two species of plant worked with, and since each was done in duplicate, at least four results were obtained for each process with each kind of plant. In some cases, where an ambiguity existed in the results obtained, a process was repeated six or eight times, and in the case of the conditions which seemed of most promise (7 hours at 104° F.) some thirty experiments were carried out in all, whilst the "ordinary" process was worked about fifteen times.

I have taken the "moorhun" and "khoontie" results together in considering both efficiency and quality since no great difference were apparent in the figures obtained during the two "mahais," and have also combined the results obtained with Sumatrana plant both at Sirsiah and Pusa. I have, however, separated the Java and Sumatrana figures for efficiency and those expressing quality in the case of the two factories. Only "moorhun mahai" was worked at Sirsiah and only Sumatrana plant used.

The temperatures used for experiment were selected for convenience at 5° C. (9° F.) apart except the "ordinary" process which was taken to imply working at 32° C. (90° F.), this being the average temperature during the greater part of mahai in most factories. If the water used was not naturally as warm as this (as was frequently the case at Pusa where the water was drawn from the river) it was raised to that temperature. No experiments were tried above 50° C. (122° F.) since it had been found that this was the optimum

for fermentation in the laboratory, and also because it was very improbable that, however good the result, working at so high a temperature could be economical. The periods of steeping tried were such as laboratory work indicated were in the neighbourhood of the optima.

The results obtained were not on the whole as concordant as could have been wished, the difficulty of controlling a process subject to so many fluctuations with sufficient accuracy being very great and the necessary sampling very difficult.

I think, however, that by taking averages of large numbers of results I have arrived at fair approximations to the true values of the processes investigated.

Interpretation of Results.

The first thing which is apparent on considering the table (see next page) is that the efficiency of the "ordinary" process is high for both kinds of plant, and that, in fact, in the case of Java, the "ordinary" process is the most efficient of those employed. In the case of Sumatrana plant a certain amount of advantage in point of quantity seems to have attached to working at 104° for 7 hours; this result requires confirmation since sufficient experiments with that plant were not carried out, the material not being available. In the case of neither plant does any advantage seem to have arisen by working at the higher temperatures; in fact, the margin for improvement over the ordinary process is not sufficiently large to compensate for the expenditure that would be necessary to work at these temperatures, unless great advantage is to be derived on the score of quality.

All this was apparent by the end of "moorhun mahai," and accordingly the "khoontie mahai" at Pusa was devoted entirely to comparing the "ordinary" process with that worked for 7 hours at 104.° These two sets of conditions were thus very thoroughly tested, and the figures representing the averages of their results, which are the most important to consider, may thus be taken to be thoroughly correct.

The "ordinary" process.

Ten hours is found to be the optimum period for steeping at 90° F. rather than 12 hours, as recommended by Rawson. In the case of Sumatrana plant, 12 hours at 86° F. seems to have given better results than 10 hours at 90° F., but the difference is small and the estimate of the efficiency of the former set of conditions is founded on only a few experiments which were, in fact, carried out in error. I think it may be accepted that 86° F. is too low a temperature to steep at under any circumstances, and that if the water is as cold as

TABLE SHOWING THE AVERAGE EFFICIENCIES OF THE VARIOUS PROCESSES EMPLOYED AND THE QUALITY OF THE INDIGO PRODUCED BY EACH.

Temperatures (in degrees Fahrenheit).	86°		90°		104°					113°			122°	
Hours steeping.	12	8	12	10	4	5	6	7	8	3	4	5	4	5
Average percentage efficiency of process for Java plant (Pusa).	70	53	66	82	36	46	72	73	72	58	64	64	76	69
Average percentage efficiency of process for Sumatrana plant (Sirsiah & Pusa).	78	..	58	72	..	78	74	84	80	..	..	..	64	71
Average percentage indigotin content of finished indigo from Java plant (Pusa).	69·5	75·4	63·5	66·7	56·7	61·4	64·7	63·5	59·4	71·2	66·5	64·2	66·5	64·2
Average percentage indigotin content of finished indigo from Sumatrana plant (Pusa).	71	..	57·2	68·5	..	54·1	58·2	65·1	..	..	..	..	61·3	..
Average percentage indigotin content of finished indigo from Sumatrana plant (Sirsiah).	..	..	..	67	..	69·4	69	69·3	69·6	..	..	..	69	..

this it should be heated in the " Kajana " to 90° F., as recommended by Rawson (Report, p. 48), and a 10-hour steeping given. Since, however, the quality of the indigo produced from Sumatrana plant by a 12-hour steeping at 86° F. was the highest average of those manufactured from that plant, I shall endeavour to repeat the experiments next " mahai."

Steeping at 90° F. for 10 hours we obtain, in the case of Java plant, 82% of the possible indigotin obtainable. It must be borne in mind that a certain quantity, estimated by Rawson at 5%, of the liquor from the steeping vat is inevitably lost to the oxidising process being left soaked up on the plant (Report, p. 46) If we accept this estimate we arrive at the conclusion that the " ordinary " process gives 87% of the possible result. This is very high efficiency and leaves a very small margin for improvement, taking into consideration the expense which such improvements must involve.

Effect of higher temperatures.

It is clear that the chemical changes in the vat liquor, previously referred to (p. 5), operated adversely at the higher temperatures of steeping, and that it is better to risk bacterial fermentation at the lower temperatures than these chemical changes at the higher ones. It seems probable that the bacteria which are found in the vat at ordinary temperatures do not operate to any extent upon the indigo-yielding substance.

Losses in seet water, etc.

It should be noted that the figures given in the foregoing table do not represent the indigo actually obtained in the factory at the finish, since, as previously pointed out, losses always take place subsequently to the oxidising process. The chief of these is in the seet water. This seems (taking an average of the analyses performed during last " mahai ") to amount to about 10% of the total indigotin produced, but, as determined by Rawson, it frequently amounts to as much as 20%, especially if ammonia or other alkali is not used in oxidising. No marked difference in settling was observed with the various processes employed in the experiments described. It would seem that there is room here for considerable improvement in " mahai," and the matter will receive attention this year.

Conclusion as regards "efficiency."

Finally, as regards efficiency, I would like to lay stress upon the point that, although I cannot recommend steeping under any but " ordinary " conditions, it is most important that the conditions which I have designated " ordinary " be adhered to. During " khoontie mahai " the temperature of the water drawn from the river fell below 80° F.; neighbouring factories using this water were

obtaining exceedingly poor yields of indigo from their plant, whilst at Pusa, by warming it to 90° F., our average efficiency was 78%. No doubt the plant contained as much available colouring-matter in both cases, but it is useless attempting to extract it with so cold water, and long steeping will not compensate for low temperature. It is also a mistake to imagine that the ferment is washed out of the plant on wet days; produce is then low mainly because the temperature is low, and it can be largely avoided by heating the water as required.

Recommendation. I would strongly advise every factory to provide a perforated steam-pipe in the water reservoir, so that in case of need the temperature of the water can be raised. As a rule, very little steam is required for the necessary work, and almost all factories are sufficiently well equipped to provide what is needed without difficulty It is preferable to heat the water in the reservoir to doing so in the "mooree," for the reason given by Rawson (Report, p. 33). A means of heating the water might be made of even greater use in factories where a long range of steeping vats delivers into one large beating vat. If it is impossible to load all the vats at once, and is yet necessary to run off all together, it follows that some of the vats are understeeped and others oversteeped. This might be avoided by gradually heating the water in the reservoir and thus supplying water at a few degrees higher temperature than the last to each batch of vats loaded. In this way the shorter steeping of the last-loaded vats would be compensated for by their higher temperature, and all would receive an optimum steeping. I have not seen this system in operation, but I believe it is being very successfully worked at at least one factory in Bihar, and the soundness of the principle is borne out by my experiments.

Another case, in which some method of heating the water will be indispensable, is in conducting "mahai" early in the year (February or March) with the cuttings obtained from Java plant, if it is pruned at this season as recommended in the latter part of this report.

Effect of hot water processes on quality. In connection with quality the hot-water processes have given more satisfactory results, in fact the indigos valued most highly by the Calcutta agents included nearly all made at the highest temperature employed. At this temperature (122° F.) giving a three-hour steeping indigo analysing 78% indigotin was obtained. The experiment is not recorded in the foregoing table because it was only carried out on one occasion, the efficiency of the process

being so low, and the cost so high, that it was discarded as impracticable forthwith. Indigos containing the same amount of indigotin as those placed at the top of the list were obtained on several occasions at lower temperatures, but their appearance is not so pleasing, and they are, therefore, valued less highly by the agents. It remains to be seen if a sufficiently high price is obtained for this indigo to repay the cost of making it. I think this exceedingly doubtful. It must be remembered that the processes employed are of a low efficiency, the cost of working is high, and, finally, their specific gravity is low, so that a large bulk of indigo goes to make a maund.

Recommendation.

On the whole I cannot recommend hot-water processes even on the score of quality. The 'ordinary' process can be relied upon to produce indigo containing an average of 65% indigotin if Java plant is used and Rawson's recommendations adhered to, and it does not seem that it will pay the planter to produce a higher grade indigo than this.

Quality of indigo from Java plant.

It is to be noted that the quality of the indigo produced from Java plant at Pusa is, in most cases, higher than that produced by the same process from Sumatrana plant. This seems to be the case at every factory where "mahai" has been carried out with both kinds of plant.

Yellow colouring matter.

A very small quantity of the yellow colouring matter described by Rawson (Report, p. 27) was present in nearly all the indigo made from Java plant at Pusa, and has been characteristic of most of the indigos made from it in Bihar this year. It remains to be seen whether this prejudices the value of the indigo in any way, and if so, how it may be avoided. The matter will receive careful attention at Sirsiah during the coming season. There is no doubt that manufacturing with immature plant tends to produce the yellow matter. This has been borne out by the experience of planters, who started "mahai" very early in the year, and is also indicated by Rawson's analyses (Report, pp. 27 and 28).

It would seem that the plant, as we now have it, contains a certain amount of yellow matter when it is capable of yielding most indigotin, and is, therefore, ripe for "mahai." The yellow substance is soluble in alkali, and indigo made by Coventry's process, therefore, contains none; but it does not seem to be altogether removed by Rawson's ammonia process though, doubtless, if an excess of ammonia were used this would be the case.

"Liminess."

In connection with quality, I should like to call attention to the

so-called "liminess," which has characterised a good deal of indigo made this "mahai." In my own case many indigos of identical value, by analysis, to those esteemed most highly, have been declared less marketable owing to their "limy" appearance. Several indigos of a similar sort from other factories have been examined, and it has invariably been found an indication of good quality. The "liminess" is, in fact, not due to lime at all, but to a growth of mould which gains access to the interior of the cake through cracks in the surface during the drying process. High quality indigos tend to crack more easily since they contain less gummy matters to bind them, and also because the "mal" tends to form a much thicker paste in draining than an inferior quality. In this way not only may air containing mould spores be retained in the interior of the cake, but also the tendency in pressing would be to form a cake, whose ends would be very hard but whose sides (corresponding to the inside of the slab removed from the press) would be soft; if this is so, the cake would be almost sure to crack and admit mould spores in drying. The remedy for this seems to be to put the paste into the presses in a moderately thin condition, so that it may press evenly and allow all air bubbles to escape. Attempts will be made to verify this conclusion during the coming "mahai."

Drying and packing indigo in forms other than a cake.

Some time will also be devoted to experimenting in methods of drying and packing finished indigo other than in the present cake form. There can be no doubt that the present form is an inconvenient one for the dyer, even though the sustained sales show that there is a demand for it. It would, no doubt, be unwise to supply natural indigo to the market in any form other than the cake, so long as this demand continues, and the peculiar form gives it an enhanced value, but this demand must become more limited as time goes on, and (especially if the outturn of indigo increases) a time must arrive when natural indigo must compete with the synthetic product on its own ground.

The first necessity will then be to supply natural indigo in as convenient a form to the dyer as he can obtain the synthesised substance, and it is a question whether, if this could be done now, a great many of the dyers at present using synthetic indigo would not return to the use of the natural product. The most hopeful way of doing this is to obtain natural indigo in powder form. Such powder could be made of various grades and sold on a guarantee of any required indigotin content up to the maximum purity which

Powder.

could be economically produced (say 70 %), and pastes or cakes of known quality could be made from it at a central distributing depôt in the country of consumption. The advantages of selling indigo in such form were pointed out by Rawson in his first report, and the reservation made by him, as regards its feasibility, still holds (Report of 1899, pp. 30 and 40). Central distributing agencies, such as I suggest, could not be organised without co-operative action on the part of planters. The present method of selling indigo seems, however, bound to decline as knowledge of the synthetic product spreads, and, unless the outturn of natural indigo is to decline with it, some such co-operative selling agency must become an imperative necessity.

I do not think it would be an economic possibility to manufacture pastes in India, the cost of shipping the wet material militating against it The "mal" as obtained on the table in the indigo factory is in the condition of as fine a paste as could be desired (*vide* Rawson's Report 1899, p. 30), and experiments which have been carried out this year have proved that it is possible to preserve it in this form by sterilisation and sealing up in tins; but I do not think this would pay. **Paste.**

What is required is a means of drying the "mal" rapidly and grinding it immediately into a fine powder, and the devising of a method of doing this will be one of the main pieces of work to be carried out during the coming "mahai."

AGRICULTURE.

Considerable attention has been devoted to the agricultural aspect of indigo during past years, but, with the exception of the introduction of Java plant, very little of the knowledge which has been gained has hitherto proved of practical utility.

Extensive experiments on the manuring of indigo have been carried out at Dalsing Serai by both Mr. Hancock and Professor Bloxam, and at Mosheri and Peeprah by Mr. Rawson. It has been shown that, in some cases, the yield of indigo plant from a given area of land, can be increased by treatment with organic and inorganic nitrogenous manures and phosphates, but this seems to be more an indication of the needs of Bihar soils than of those of indigo in particular, since almost any plant will respond similarly to like treatment on our soils. It is a question whether it would pay, as a general practice, to apply nitrogenous manures to indigo, **Manuri**

since, being a leguminous plant, it is capable of providing itself with nitrogen from the atmosphere. Organic matter is of undoubted benefit in stimulating growth, but results so far obtained seem to indicate that, by growth in a richly organic soil, the colour-content of the leaf decreases, whilst phosphates, though undoubtedly of value in some cases, are expensive and their results uncertain. The knowledge so far gained would prove of great value, however, if it could be coupled with treatment specific to the production of indigo-yielding material in the plant.

Method of conducting manurial experiments. The results obtained in manurial tests, on experimental plots, have hitherto been very anomalous. This seems attributable to two causes. In the first place the nature of any large area of land in Bihar is such that it is almost impossible to divide it up into experimental plots of equal natural fertility. In the second place, mere weighment of the plant obtained from a given plot, even if supported by estimations of leaf-content, is misleading as an indication of the value of any manurial treatment (since a large weight of apparently fine plant will frequently give less dye than a smaller weight of stunted plant), and neither manufacturing trials in small vats nor in kiers, as designed by Rawson, can be relied upon to give trustworthy estimates of the indigo which can be obtained from the plant under experiment, the conditions being so widely different from those occurring in ordinary manufacture.

There seem to be only two methods of attacking the problem likely to lead to trustworthy results. Either to conduct manurial trials over such large areas, that the natural inequalities of soil become negligible, and the yields of plant sufficiently large to be dealt with on a manufacturing scale, or to carry them out on such small plots that the soil can be artificially made up so as to ensure the same normal conditions in each plot, and to rely on analysis and determinations of leaf-content for evaluations of the plants resulting from the various manurial treatments. The former course is obviously impracticable where many experiments have to be conducted. The latter is under trial at Sirsiah this year. Several holes, 1 yard square and 2 feet deep, have been dug in a fairly uniform piece of land and the soil from them thoroughly mixed and returned to the holes, the manure under experiment has been mixed with the top six inches of soil and the plots sown with Java indigo. Care will be taken to obtain an equal number of plants equidistant from one another on each plot. The general object of the experiments is to see whether there is any specific chemical substance which will lead

to an increased production of colour-yielding material in the leaf. As is pointed out above, we already know how we can stimulate the growth of the plant and so obtain a heavier yield per acre; if, in addition to this, a means of directly increasing the content of colour-yielding material in the leaf can be devised, or even of sustaining the normal content whilst increasing the growth of the plant, a profitable means of manuring may be evolved.

Soil inoculation.

Experiments in inoculating the soil with indigo-nodule bacteria have been started on similar lines to the manurial ones. Details of both will be given in my next report when some results have been obtained.

Selection.

At present a more hopeful means than manuring of increasing the yield of colour, from unit area of land, seems to be by selection of plant. The replacement of the ordinary (Ind. *sumatrana*) plant by the Java variety (Ind. *arrecta*) has already proved of widespread benefit and will be dealt with later, but it is at present premature to focus our hopes entirely on Java plant, since we do not yet know whether it can be universally grown to the entire exclusion of the old variety. On the contrary, it seems probable that a certain amount of Sumatrana plant will always be needed to sow in low lands, which are not ready for cultivation in October, and do not hold their moisture sufficiently well to be sown in March. In any case it is doubtful whether all the lands in a large concern could be prepared in time to sow Java indigo in October and November except at the cost of a rainy-weather crop.

Selection of Sumatrana pant.

Meanwhile much remains to be done in the improvement of the ordinary plant. It has been pointed out by Mr. Leake (Report of the Dalsing Serai Research Station, 1903-4) that the plant ordinarily grown as *Indigofera sumatrana* is, in reality, a mixture of several subvarieties of very different values, some possessing a large leaf area and others a very small one, some flowering and developing early and others late, and so on. It is most important that the best of these subvarieties should be selected and grown and the others excluded. Mr. Leake suggests that this should be done by deriving seed from only those areas which are found to supply the best plant; he points out, however, that a final criterion of what is the best plant must depend upon leaf analysis, for which, at the time of his writing, no suitable means existed.

Several of the subvarieties isolated by Mr. Leake were grown at Pusa last year, but opportunity occurred for analysis of only two of them, and these rather late in the season. The seed from each of

them has been, collected and sown at Sirsiah, and their respective values as indigo-yielders will be determined during the coming season.

It is doubtful whether it will be possible to obtain a pure strain of whichever turns out the best variety, by deriving more seed from the quarter whence the plant was originally obtained. The mixture of varieties has, of course, arisen from the fact that mixed seed has been sold in the North-West markets from time to time, and probably no one area is now growing a pure strain. In this case it will only be obtained by carefully controlled selection. This would be very difficult to conduct in the North-West, since it would need constant scientific supervision. I had intended endeavouring to select from the ordinary indigo grown at Sirsiah from seed produced at the seed-farm at Dasna last year, but time did not permit of it. I hope that, with the assistance of a trained botanist, something will be done in this direction during the coming season. Experiments will also be undertaken, if possible, in hybridising selected varieties.

Production of Sumatrana seed in Bihar.

Seed from the best plants will then be grown at Dasna, if it proves necessary to continue the cultivation of Sumatrana seed in the North-West. Experiments are now in progress which will determine this point. Several planters have kindly offered to grow Sumatrana seed and send it to me, and I shall then be in a position to exchange it between factories, at a distance from one another, and to judge of the difficulties which are said to exist in growing seed so obtained. So far as I can gather these are three-fold. Firstly, there is said to be difficulty in germination; secondly, that the plant is delicate and unable to resist the hot weather drought; and, thirdly, that its produce is poor. If the first contention is true, it should be easily overcome by scarifying the seed in the manner which will shortly be practised by every planter with Java. The second and third points are more important, and can only be judged of by direct experiment which will be carefully conducted during the coming season. I think, however, that by organising an exchange system for Sumatrana seed, on the same plan as it is now proposed to adopt for Java, these difficulti s might also be overcome.

If the cultivation of this seed in Bihar prove feasible, its selection will be very much simplified since it can then be conducted at the seed farms which it is now proposed to establish, and controlled by the Sirsiah staff.

The advantages of having the seed-supply under the control of planters has been sufficiently demonstrated by the results obtained

with ordinary seed grown at Dasna, in 1904, and sown in Bihar last season. No selection was carried out, but the plant was carefully grown, the seed carefully harvested from "moorhun" plant, and the adulterations characteristic of North-West seed bought in open market excluded. The result was a sample of seed of about 95% germination-capacity which could be sown at the rate of 5 seers per acre to give a full crop. This was the case at Sirsiah, and has been confirmed by the experience of planters, to whom a small portion was supplied.

Advantages of planters controlling their own seed supply.

Similar seed has been grown at Dasna during 1905 and has just arrived in Bihar. In the cultivation of this certain experiments were tried in methods of growing seed. The object was to determine whether any advantage attached to thinning the plant before seeding commenced, it being thought possible that branching would be set up and an increased yield or, possibly, a seed of greater value be so obtained. The results have shown that the ordinary practice in the North-West of growing a thick crop gives the heaviest return. It is very doubtful whether any improvement in quality will be apparent in the seed grown under the thinning-out p'an. The whole of the area available at Dasna (50 acres) is to be devoted to the cultivation of Sumatrana seed this year. This course seems justified by the results already obtained, and the undesirability of continuing the cultivation of Java there (see p. 26). If possible some selection of plants, as above described, will be carried out, but this will depend on whether the services of a botanist are available for the work.

Operations at the Dasna seed farm.

The introduction of the Java plant has been by far the most important improvement in the agriculture of indigo within recent years. The advantages attaching to its cultivation are already so well known that is hardly necessary to recapitulate them ; lest, however, there are some planters who are not fully acquainted with them, I will quote from a letter on the subject from Mr. B. Coventry, of Pusa, which was attached to my preliminary report in February last.

Java plant.

"I. It has not only much more colour in the leaf, but more leaf per weight of plant if this is taken on samples strictly comparable. The yield per acre is, therefore, straightway increased without adding to the cost of production.

II. It flowers and fruits after "mahai," so that the growth of the plant is not wasted by producing flower and seed during "mahai."

III. By containing more colour in the leaf, the cost of manufacture per maund is lessened by reason of the yield per vat being greater.

IV. It can be sown in September and October when germination can be secured, and, consequently, the percentage of empty lands should be very small in any year.

V. The cultivation charges are less.

VI. It can no doubt be grown as a mixed crop but that has not been worked out yet.

VII. Planters can grow their own seed of which they need only sow 5 seers per acre, thereby effecting a considerable saving on that head.''

So far as my experience goes I can fully confirm all these claims if reservation be made with regard to No. 7. I will refer to this point later on.

Results at Pusa.

In a note published in October last the results obtained with Java plant at Pusa were summarised, and it was then pointed out that its superiority both in point of leaf-content and colour-yielding material in the leaf was largely masked by the fact that '' mahai '' was unavoidably delayed, until a large proportion of leaf had dropped and the plant attained an overripe condition.

Thus the average leaf-content during '' moorhun mahai '' was only 30%, and during '' khoontie mahai '' 41%, whilst a fair normal average for Java plant all round is between 50 and 55%. Again the average of the analyses of Java leaf, carried out during both '' mahais,'' showed a content of ·54% indigotin, though it should certainly have been above ·6%, judging by other analyses of leaf from plant in a fully ripe condition. In addition to this, low yields of indigo were frequently obtained when unsuccessful manufacturing experiments were carried out, and its specific gravity was frequently lower than normal (see p. 15), so that the gross produce is not directly comparable with that of an ordinary factory.

The Pusa results cannot, therefore, be taken as typical. Nevertheless the yield of Java leaf per acre averaged 52 maunds, whilst that of Sumatrana was only 36 maunds, and an average of 12·7 seers of 65% indigo per acre was produced from the former and only 8 seers from the latter. These figures are derived from the analyses of oxidised liquor (Column VIII in daily record table, p. 9), and therefore do not take seet water losses, etc., into account. As deduced from actual weighments of finished indigo, the Java gave 9·6 seers (of indigo of various qualities averaging about

65% indigotin) per acre, and the Sumatrana 6 seers. This is exclusive of washings. By both methods of reckoning, therefore, the Java plant has given an increase on the area of about 60% over the Sumatrana.

These figures should be sufficiently convincing for the most sceptical, and, so far as I have heard, they have been fully confirmed by the experience of all planters who have manufactured from Java plant last season. Thus, at Dalsing Serai, where I believe the largest cultivation of Java plant in Bihar at present exists, Mr. Coventry writes me he obtained an increase of as much as 95% in the yield of indigo per bigha obtained from that plant as compared with the ordinary variety. Similar reports have been received from other quarters.

Quality of indigo made from Java plant.

The quality of the indigo obtained from Java plant has been, so far as I am aware, in every case good. Judging by those I have analysed the quality has been almost universally better than that of the indigo made at the same factory from ordinary plant.

The figures quoted in the first part of this report show that this was the case at Pusa where all the indigo valued most highly by the Calcutta agents was made from Java plant.

Cultivation of Java plant.

There can thus be absolutely no doubt of the advantages that attach to the Java plant, but much yet remains to be learnt about its cultivation.

'Natal' and 'Java' plant.

In the first place there seems to be some doubt as to the difference, if any, which exists between 'Natal' and 'Java' indigos. As a matter of fact, they are the same thing. Both are botanically *Indigofera arrecta*, but the plant is a native of Natal and has only been introduced into Java by the planters there. It has now become acclimatised in Java and has been carefully cultivated and probably selected to some extent there, so that some advantage has attached to getting our original seed thence instead of from Natal.

Germination.

The difficulty of inducing the seed to germinate in Bihar has now been fully overcome by the introduction of scarifying machines which, by scratching the hard seed coat, allow of the entry of moisture into the seed and so promote germination. It may not be out of place, however, to reiterate the caution that no attempt should be made to sow unscarified seed under any circumstances. In a few cases germination has been obtained without scarifying, but the result is far too uncertain and the necessary cost and trouble of conducting the operation too small to be worth risking failure. It has proved impossible to produce a seed which will germinate

without treatment by growing it in the North-West, seed grown there having just as hard a coat as that produced in Bihar. It may be possible to do so by selection, and it will be tried at Sirsiah this year. It is not unlikely, however, that even if this can be done it will be at the cost of other valuable characteristic of the plant, and in any case it must take time. Meanwhile scarifying should be universal.

The germination capacity of all seed should be tested before sowing in the manner described in a recent circular: it is impossible to judge of the efficiency of scarification or of the value of the seed in any other way.

Sowing season.

Certain differences of opinion still seem to exist among planters as to the best season for sowing Java indigo. Such a question depends so entirely upon local conditions that this is not surprising. There can be no doubt that the months most generally to be recommended are September, October and November. It has been shown possible, however, to go on sowing and obtain good germination until January, whilst some planters find that March sowings give perfectly satisfactory results. I would not recommend this, however, except on exceptionally good moisture-holding lands and in good moisture years. Experiments carried out at Pusa have shown that sowings on irrigated lands answer well up to the middle of April.

Cutting back in February or March.

Another point which has been clearly demonstrated by experiments at Pusa is that plant sown in October and November should invariably be cut back as close to the ground as possible in February or March. Plant so cut back throws out new shoots from below the ground, so that it has a much higher leaf-content when ready for "mahai" than if the original stem is allowed to thicken and form wood. Another advantage is, that, by avoiding the development of a thick stem, the plant is easy to cut and is not so hacked in the process whereby considerable loosening of the roots is likely to take place, especially after a rain, and the plant killed or seriously set back.

It is no doubt possible to manufacture from the cuttings if the precaution of heating the water recommended in the first part of this report is taken. This will be tried at Sirsiah next season. The yield to be expected is, of course, not so large as would be obtained from an equal weight of ripe plant, but it should repay the cost of manufacture.

The exact time when the plant is ripe, that is to say, when it is

Madras

Cutting season.

capable of yielding the maximum amount of indigo, is a point yet to be determined. Rawson's figures for transplanted plants analysed at different times of year showed a maximum content of indigotin during April, May and June, during which months the content was fairly constant (Report, p. 29). It is probable, therefore, that planters do not go far wrong in manufacturing from it during the ordinary "mahai" season, and that the disappointing results which were obtained in some cases where manufacture was started early, are to be mainly attributed to the low temperature of the water employed. Analyses of plant growing under ordinary agricultural conditions will be carried out at Sirsiah at intervals during the coming season

Method of growing Java plant.

Some experiments were arranged at Pusa to determine whether any advantage attached to thinning Java indigo, and, if so, to what extent this should be done, also if topping (pinching off the growing shoots) of the plants led to any increase in growth. Plots of $\frac{1}{25}$ acre each were selected from a fairly uniform field and treated as shown in the following table in the middle of May. Half of each plot was cut at the end of June and the plant weighed. The weights obtained were as shown. Each plot was duplicated and the results obtained were fairly uniform. The figures given are the averages of the two results in each case.

Method of treatment.	Yield of plant from 1/50 acre.	
	M.	S
Untreated	2	36
Topped..	3	1
Plants thinned to 1′ apart	2	8
Plants thinned to 2′ apart	1	2
Plants thinned to 3′ apart	0	29

The results show that practically no advantage in point of yield of plant attaches to either of the methods of treatment. The small increase where the plant was topped is within the range of experimental error, and even if constant would not repay the cost of the operation.

Opportunity did not occur to determine the leaf-content of the plant in each case, but there was no obvious advantage in this respect on the treated plots. I am led, therefore, to agree with the opinion expressed by Mr. Coventry in his letter of February last previously referred to, that as thick a crop of Java plant as possible should be grown for "mahai" purposes. This should be attained with good seed by sowing at the rate of 5 seers per acre.

Number of years during which plant can be used for manufacture. Another question awaiting solution is the number of years a Java crop may be left in the ground and cut for manufacture without undergoing deterioration. This can, of course, only be determined by experiments extending over some years. Plant at Dalsing Serai has given far finer returns during its second year than its first, but, although third year plant was used for manufacture last season, no records of its original value are available for comparison.

Method of growing Java Seed. It is very improbable that the method of growing plant for manufacturing purposes which has proved best will also be most advantageous for cultivating seed. It had been intended to leave the second half of the plots above described for seed yield, but they were unfortunately cut in error during "khoontie mahai." Experiments on the subject will be undertaken at Sirsiah this year.

Seed supply. The production of Java seed is a most important question and merits the close attention of planters. It has been proved by the experiments which have been conducted during the last two years at Dasna, that no obvious advantage attaches to growing it in the North-West districts. The experiments were undertaken in the hope that a thin-coated seed which would germinate under ordinary March conditions in Bihar might be produced. It has already been pointed out that this has not proved the case, nor has the plant thriven better in any respect than it does in Bihar; on the contrary, the risk of injury from frost before the seed is ripe is greater in the North-West, at least half the crop having been lost from this cause during the past two years, and the seed produced has no better appearance or germinating power.

Production in Bihar. The advantages of producing seed in Bihar itself are obvious, and all that has previously been said with regard to Sumatrana applies here with even greater force. Nevertheless, I consider it is a great mistake for planters to grow their own seed as is rapidly becoming customary, and this for the following three main reasons :—

I The principle of growing seed on the land on which it has been produced tends to rapid deterioration of strain and is fundamentally opposed to all agricultural principle.

II. The most advantageous method of growing plant for manufacture is almost certainly not the best way to cultivate it for seed.

III. The temptation to derive seed from the second growth of the crop, after a cutting has been taken for manufacture, is great and must certainly lead to the production of poor seed.

It is difficult to bring figures and data to prove these assertions. In support of the first I can only point to general principles and to the almost universal custom amongst farmers of all countries of importing their seed from outside their own farms. Nearly all cultivated plants are the products of artificial selection, and acclimilisation of some sort or other, and their tendency is always to revert to their original condition. Java indigo is no exception since it is derived from the wild indigo of Natal. It is well known that this reversionary process is hastened by continually growing the plant from seed produced on the same land, and under the same climatic conditions, and may be very largely avoided by exchanging seed between different localities. It is, therefore, to be anticipated that, if planters continue to grow their own seed, so much deterioration will have taken place in a few years that only a tedious process of selection or fresh importations of seed from Java will restore the present condition.

It has been suggested that planters should exchange seed amongst themselves to avoid this contingency, and no doubt if this were done it would be of very material benefit. The objections which I have numbered I. and II. would still hold under those circumstances. Every planter will, naturally, want to use as much of his Java plant as possible for manufacture, and will grow it so as to obtain as heavy a crop as possible. It yet remains to be seen whether this method of cultivation will also lead to the heaviest seed-yield, but it is very improbable that this will prove to be the case since a close crop will not permit of the branching and consequent entry of light and air so necessary for efficient flowering and ripening of seed. Still less likely is it that the seed so produced will be of the best quality unless each plant has ample room from which to draw its nourishment. In this case poor seed will be grown and the bad qualities accentuated with each generation. Even more will this be true if seed is derived from plant which has been cut back for "mahai." It is not to be anticipated that a plant which has been so set back in its growth will produce healthy seed, yet I have heard of planters who have gone so far as to take two cuttings for manufacture and derive their seed from the third growth!

If planters would each establish a small seed-farm and there grow their plants under the optimum conditions for the purpose and exchange their produce amongst themselves, no doubt all would be well. But I fear this is impracticable, and, as an alternative, have suggested the establishment of farms at distances as remote from one

another as possible in Bihar, where seed should be grown under the direction of the Sirsiah staff for distribution to planters. In this way the results of the experiments in cultivation carried out at Sirsiah could be put into effect at once, the seed could be carefully grown and selected, and, above all, could be so distributed as to ensure a change of environment between place of production and of sowing. For the successful working of such farms it will be necessary for planters to support them by obtaining their seed thence instead of using their own or by mutual exchange, but it is hoped that the advantages of so doing are sufficiently apparent to ensure this.

An urgent need for selection.

Pending the establishment of these farms the Java plant is bound to be increased from seed already in circulation, and I would, therefore, like to call the attention of planters to an urgent need for selection amongst their plant which might easily be carried out by each for himself. In any field of Java indigo at least two types of plant can be found, having not only different habits of growth, but entirely different seed pods, and it is by this latter characteristic that they are most easily differentiated. The illustrations will make the difference perfectly clear.

The plant with spikes of curved seed pods is Indigofera anil, the species commonly known as Madagascar indigo; the other is Java indigo. The former is a comparitively poor colour-yielder and should be carefully weeded out wherever found, otherwise it will go on increasing year by year and will, in any case, lower the aggregate yield from a field of Java indigo and may even thrive at the latter's expense and gradually replace it. There are very probably other foreign varieties to be found amongst the Java plant; so far, however, this is the only case to which attention has been drawn. Care would be taken at the proposed seed-farms to eliminate all such impurities.

nalyses of ırious ırieties of digo.

The following analyses and determinations of leaf-content of several varieties of indigo grown at Pusa, all on the same soil and under precisely the same conditions, show their relative values a indigo yielders :—

Variety.		Percentage leaf-content of plant.	Percentage content of indigotin in leaf.
Java (Ind. arrecta)		52·2	1·05
Ind. longiracemosa		46·7	·681
Natal (Ind. arrecta)		52·9	·667
Coconada (species ?)		43·8	·663
Madras (species ?)		41·9	·611
Guatamala (Ind. oligosperma)		50·7	·582
Madagascar (Ind. anil)		46·9	·574
Ordinary Bengal indigo (Ind. sumatrana).	Multan subvariety	30·9	·585
	Delhi ,,	36·9	·542

The superiority of Java and inferiority of "ordinary" indigo are apparent from this table, as also is the improvement which the wild Natal plant has undergone by cultivation in Java, whilst the poor quality of Madagascar indigo justifies the above advice with regard to the necessity for arresting its spread in Bihar. The variety which shows the nearest approach in point of indigotin content in the leaf to Java, *Indigofera longiracemosa*, was obtained from Madras with the reputation of being very rich in colour-yielding material. This is seen to be justified to some extent, but it falls far behind Java plant and its percentage leaf-content is also very low. Its cultivation, cannot, therefore, be recommended.

In conclusion I wish to express my thanks to Messrs. Briggs and Finlow for the assistance they have rendered in the work which has been described, and to Messrs. Macgregor and Rawlins for their careful attention to the many practical details involved in carrying out cultivation and manufacturing experiments.

REPORT

OF THE

INDIGO RESEARCH STATION, SIRSIAH,

(*Under subsidy from the Government of Bengal.*)

FOR THE YEAR 1906–1907

BY

CYRIL BERGTHEIL.

INTRODUCTION.

THE past year has been an unfortunate one for indigo investigations in the field and factory owing to the heavy floods in August. The indigo crop at Sirsiah was entirely destroyed, and a number of experiments which had been planned for "khoontie mahai" had to be abandoned, whilst several agricultural experiments were destroyed or their results rendered doubtful. I shall have occasion to refer to this again in the course of this report.

Laboratory work has proceeded satisfactorily and several investigations have been brought to a conclusion. I propose reporting briefly on this work first and dividing the remainder of the report into two main sections dealing respectively with manufacture and agriculture, as in that of last year.

LABORATORY WORK.

Results of Investigation into the methods of determining Indigotin.

The results of the investigations into the methods of determination of indigotin in commercial indigo and indigo-yielding plants were published in a paper by Mr. Briggs and myself which appeared in the Journal of the Society of Chemical Industry of August 15th last. We have shown therein that Rawson's permanganate method gives absolutely correct results with pure indigotin, but that it is subject to a small error when applied to commercial indigos. This would not normally amount to more than 2-3 per cent., so that conclusions which have been drawn from the application of the method to problems of indigo manufacture have no doubt been quite sufficiently reliable. We have shown how the greater part of this error may be avoided, and that in the method as modified by us it is extremely improbable that an error of more than 1 per cent. occurs in the analysis of an indigo of average quality. Approximately the same degree of accuracy is obtained with the other methods of analysis investigated, but the permanganate method is found to be the most expeditious and best in all but exceptional cases.

Bloxam's investigations.

Simultaneously with the publication of the above-mentioned paper there appeared one by Mr. Bloxam on the same subject. Mr. Bloxam's conclusions are so startling, and so at variance with both Rawson's and my own, that it is necessary to consider them in some detail here.

In the first place it is pointed out that Rawson's permanganate method is valueless for accurate determination of indigotin in crude indigo, though it is now admitted that it gives correct results with pure indigotin.* It has been shown that the statement with regard to the determination of indigotin in crude indigos is correct as applied to the method in the form published by Rawson, but that by a very trifling modification it may be rendered accurate within 1 per cent. Mr. Bloxam does not, however, attempt to modify the method but considers the process of sulphonation involved is erroneous and proposes a new method of sulphonation by means of which he states that indigotin, both pure and in crude indigo, can be accurately determined for the first time.

There is absolutely no evidence in his paper in support of either of these assertions; on the contrary, the admission that Rawson's method can be relied upon as it stands for determining pure indigotin, involves a recognition, not only of the validity of his method of sulphonation, but also of the fact that pure indigotin could be correctly determined before Bloxam's method was described. The latter method has been very carefully investigated by Mr. Briggs and myself, and the results communicated to the Society of Chemical Industry for publication; we have shown that it is not reliable as it stands either in application to pure indigotin (with which results, showing a content of about 93·5 per cent. are obtained) or to commercial indigo.

As a result of the employment of this inaccurate mode of analysis, Mr. Bloxam draws certain conclusions with regard to the efficiency of the indigo manufacturing process. He analyses the indigos turned out daily during the "mahai" at Pemberandah factory in 1903-1904, the analyses probably averaging about 5-6 per cent. too low; he takes the weight of plant put into the vats and the estimated daily outturn of indigo from the factory "mahai-book," the former figure being probably only very approximate and the latter certainly so (since it was derived either from cake-measurement or from weighment of packed chests, as no separate weighments of daily produce were made at Pemberandah in 1903); he makes the

* *Vide* Bloxam in his "Account of Research Work in Indigo carried out at Dalsing Serai Research Station from 1903 to March 1904," p. 28; and in the "Transactions of the Chemical Society," 1905, p. 986, in which directly contrary statements are made.

startling assumption that the plant contains 0·6 per cent. of available indigotin, whilst in point of fact the content of the ordinary (Sumatrana) indigo plant is rarely so high as 0·3 per cent.; and from these data he concludes that the average efficiency of the manufacturing process is 25 per cent. Surely, further comment were superfluous.*

Trade Analyses.

Having satisfactorily established a reliable method of determining indigotin in commercial indigo, it seemed to me that it would be of both interest and value to ascertain how near the trade analyses performed at the main indigo-distributing centres approached the truth.

To this end, seven samples of commercial indigo of graded purity and carefully dried and sealed up in bottles, were sent to each of four analysts in Calcutta, Bradford, Manchester and Berlin, respectively. The following estimations of the percentage of indigotin in the samples were returned:—

	Calcutta.	Bradford.	Manchester.	Berlin.	Correct analysis.
I (B.A.S.F. 1898) ..	90·6	96·0	70 7	91·59	98·1
II ..	71·15	75·0	60·1	70·56	77·13
III ..	65·6	69·6	54·3	66·69	70·4
IV ..	63·7	69·0	52·9	67·24	69·45
V ..	56·9	60·0	45·8	56·03	62·13
VI ..	54·35	53·4	45·8	45·65	55·6
VII ..	46·5	45·6	41·3	38·25	47·14

It will be seen that considerable error exists in all the analyses and that all are too low. The nearest to the truth are those obtained in Bradford, in which case no doubt Rawson's method was employed. I have had some correspondence with the Calcutta analyst, from

* *Vide* Rawson, in the "Journal of the Society of Dyers and Colourists, xxii., p. 306 (quoted in the "Indian Planters' Gazette" of November 3rd, 1906); also Knecht, in the "Journal of the Society of Dyers and Colourists," xxii., p. 330, and my letter to "Nature" of November 8th, 1906.

which it transpires that he was aware that the standard on which his method was based was not such as to lead to the truth, but was the outcome of a trade convention. He has now, with the approval of the trade in both Calcutta and London, consented to adopt the method laid down by us, and his results will no doubt be correct henceforward. A leading firm of analysts in Bradford will also make use of the method, and it will probably be generally adopted in England. It seems impossible to do anything to remedy matters on the Continent at present, but this is of less importance and may be possible in the future.

Dye-tests.

A further outcome of the establishment of a reliable method of determination of indigotion in commercial indigo has been an effort to determine the precise value in the dye-vat of the substances other than indigotin which occur therein. Considerable time has been spent in an attempt to devise a method whereby the value of an indigo could be correctly established by a dye-test on a laboratory scale, but hitherto without much success. It seems to be impossible to carry out dye-tests on a small scale with anything like the degree of accuracy obtained in an analytical method, so that determination of the true dyeing-value of indigos of known indigotin-content is very difficult. This, and an effort to devise a reliable method for determining indigotin on the dyed fabric, will be the subjects of further laboratory work.

I shall refer to other work which has been carried out in the laboratory in the subsequent sections of this report.

MANUFACTURE.

Comparitive merits of steeping for 10 hours at 90° F. and for 7 hours at 104° F. for both Sumatrana and Java plant.

Almost the whole of the "mahai" we were able to carry out was occupied with confirming the results with regard to efficiency under varying conditions of steeping given in last year's report. I pointed out there that although steeping for 7 hours at 104° F. had given considerably better results with Sumatrana plant than steeping for 10 hours at 90° F., the results were based on an insufficiency of experiments which would require amplifying this year, and further, these results were reversed when the processes were applied to Java plant.

The greater part of "mahai" was therefore devoted to comparing these two sets of conditions with the two kinds of plant, reserving experiments in the settling of seet-water and some others for "khoontie mahai," which floods unfortunately rendered

impossible. Precisely the same mode of conducting and controlling "mahai" and of calculating results was pursued as that described in last year's report. The following table shows the results obtained:—

Kind of plant.	Average percentage Efficiency.		Average percentage indigotin-content of indigo.	
	10 hours at 90° F.	7 hours at 104° F.	10 hours at 90° F.	7 hours at 104° F.
Sumatrana ..	75·9	85·4	73·1	69·1
Java ..	65·3	75·8	68·5	67·9

Conclusion with regard to Sumatrana plant.

Last year's results with Sumatrana plant are thus confirmed, the figures obtained agreeing very closely with the former ones. The best steeping conditions for Sumatrana plant are therefore undoubtedly 7 hours at 104° F. Whether it will pay the planter to provide any special installation for raising the temperature of his water to this height may be questioned, though if a steady increase of 10 per cent. over his normal outturn could be relied upon (as seems to be indicated by the constancy of the figures obtained), it should do so.

The average weight of indigo turned out from 100 maunds of Sumatrana plant at Sirsiah this year by steeping for 7 hours at 104° F. was, as determined by analysis and expressed as 60% indigo, 16 seers 12 chittacks, and by steeping for 10 hours at 90°F., 15 seers 3 chittacks; whilst actual weighments showed 13 seers 5 chittacks for the former process, and 11 seers 5 chittacks for the latter. Thus the process involving the use of the warmer water has given an increase of 10·5 per cent. reckoned from the analytical figures, and of 17·7 per cent. reckoned from actual weighments. The difference between the weights deduced from analysis and those actually obtained represent losses in the processes subsequent to oxidation (*e.g.*, in seet-water, strainings, etc.), but these are not quite so high as would seem from the above figures since the average quality of the indigo made was more nearly 70% than 60% indigotin (see table); the losses are, however, undoubtedly considerable, as is only to be expected in working so small a factory (see Rawson's Report, pp. 65 & 66).

Most factories are sufficiently well equipped to raise the tempera-

Recom-mendation.

ture of the steeping water through 20° F. without difficulty, especially if the water is heated in the "mooree," and in these cases I would strongly advise steeping Sumatrana plant for 7 hours at 104° F. as a routine method.

Conclusion with regard to Java plant.

The results obtained with Java plant are more puzzling. Here we find last year's results reversed and 7 hours at 104° F. giving considerably better results than the other conditions, just as in the case of the Sumatrana plant. The efficiencies, too, are much lower than those obtained under similar conditions last year. I think this is undoubtedly due to understeeping, and that the results obtained last year at Pusa were misleading owing to the poor quality of the plant used. It will be recollected that "mahai" was started very late last year and that the Java plant was considerably overgrown, with the result that the average leaf content was about 35% and the average indigotin content of the leaf was only ·54 per cent. The plant used at Sirsiah this year was in good condition, and the average leaf content was 56% whilst the average indigotin content of the leaf was ·738 per cent., so that there was evidently considerably more indigotin to be extracted during the steeping operation. It is plain that neither 10 hours at 90° F. nor 7 hours at 104° F. was sufficiently long for the purpose, and, although the yield of indigo was very high (averaging by analysis of vat liquor and calculation as 60% indigo, 21 seers 9 chittacks per 100 maunds of plant under the former conditions, and 26 seers 6 chittacks under the latter; or 18 seers 5 chittacks in the one case, and 22 seers 9 chittacks in the other by actual weighment—considerably more in both cases than at Pusa last year), a very large amount of available indigotin was left behind in the plant and the efficiency of the processes thus rendered low. This is confirmed by the figures obtained on a particular day during this year's "mahai" when the quality of the Java plant happened to be exceptionally low, the leaf content averaging only 43 per cent. On this day the efficiencies of both processes were high, and the relation between them was the same as that of last year, 10 hours 90° F. giving an efficiency of 92·2 % and 7 hours at 104° of 89·3 %.

It thus remains an open question which is the best temperature at which to steep Java plant; it is certain that at either temperature a longer period than was given is required. I had intended experimenting further in this direction during "khoontie mahai," but floods prevented this. Only one day was available for trying

longer periods of steeping, and on this day periods of 10, 12, 14, and 16 hours were tried, the average temperature being 87° F.; the efficiencies of the processes were as follows :—

10	hours'	steeping	—71·3 %	efficiency.
12	,,	,,	—75·9 %	,,
14	,,	,,	—82·7 %	,,
16	,,	,,	—70·7 %	,,

These figures would seem to indicate that 14 hours are necessary to obtain the best results at the temperature dealt with (87° F.), whilst 16 hours is too long, so that probably 12-13 hours would be sufficient at 90° F. The matter requires carefully going into and I shall hope to do so next "mahi."

Recommendation.

Meanwhile I would tentatively advise that Java plant should be steeped 12-13 hours at 90° F. and about 8 hours at 104° F. Which of these sets of conditions will give the best results I am unable at present to say. This applies, of course, only to Java plant in good leafy condition; if the plant is overgrown and sticky no doubt the results obtained at Pusa last year are a safe guide, and 10-11 hours at 90° F. will be found sufficient.

Quality of indigo made by steeping for 10 hours at 90° F. and for 7 hours at 104° F.

All the indigo made during this "mahai" was of uncommonly good quality. It will be seen that in point of indigotin content there is very little to choose between those indigos made by the 90° F. steeping process and the 104° F. one. In the cases of both the Sumatrana and Java plant the quality is slightly higher at the lower temperature, but the difference is too small to be worth consideration, more especially in judging between indigos of such high grade.

Indirubin.

The indigo made from the Sumatrana plant by the 104° F. steeping process is remarkable as containing in almost every case a fairly high proportion of indirubin (about 3-4% on the average); the same is true of the Java indigo, but in its case the high indirubin content occurs in the indigos made by both processes and is, on the average, somewhat higher, amounting to nearly 5%. The presence of this constituent is of undoubted advantage, but it is probably to be attributed more to the employment of ammonia in oxidising than to any peculiarity of the plant or the steeping operation.

"Liminess" and "Flakiness."

A great many of the indigos were what is technically known as "limey and flaky." This condition is an undoubted accompaniment of good quality and is difficult to avoid in high grade

indigos. It is caused partly by the lack of gummy impurities which act as binding material, and partly by the thickness of the "mal" obtained when indigo of high quality is boiled, especially if boiled with acid. Both these causes lead to the formation of cracks in the cake during drying which allow of the penetration of mould spores (see last year's report).

Yellow colouring matter.

Mere traces of this substance were to be found in the indigo made from Java plant this year; so little as to be entirely negligible even if it were a harmful constituent. As a matter of fact some recent experiments in the laboratory have indicated that the yellow dye is not fixed on fabric dyed with indigo containing a great deal of it, so that it seems to be an entirely inocuous substance. The view that the content of the yellow matter is increased by manufacturing with immature plant was confirmed by the result of the "mahai" which was carried out with cuttings taken in March from Java plant. This contained an abnormally large amount of the constituent. In this connection I may mention that certain white spots which have been observed in some Java indigos are in no way connected with the yellow substance. They appear to consist of some sort of mineral matter, but in any case are a negligible factor.

Heating water for steeping to 90° F.

No opportunity occurred of comparing the effect of steeping at 86° F. for 12 hours with that of steeping at 90° F. for 10 hours, the water being naturally above 86° F. during the whole of "moorhun mahai."

I do not think there can be any doubt that it is of advantage to heat the water to 90° F. as a routine method. Several planters have done this during "khoontie mahai" and are unanimous as to its advantages. In one case an average yield of 17·4 seers of finished indigo per 100 maunds of Java plant was obtained during 12 days "mahai" extending from October 13th to October 24th.

Method of heating water for steeping.

I have had several queries in the course of the year as to the best means of heating the water for steeping and of registering its temperature, and I have had an opportunity of seeing the installations for this purpose at several factories. In most cases it seems impossible to heat the water in the reservoir in the manner recommended in my last year's report owing to the size of the reservoir or insufficient boiler power. The difficulty can be surmounted by

partitioning off a section of the reservoir, and this principle has been adopted with complete success in one installation I have seen, but it involves a certain amount of expense, and delay is apt to be occasioned by the repeated refillings of the partitioned section.

I have therefore experimented with heating in the "mooree" and found that with care quite satisfactory results may be obtained. The method requires more careful supervision than if the reservoir is heated, since otherwise the uneven heating, referred to in last year's report (p. 14), is very apt to result, but the desired temperature can be attained with very much less expenditure of steam.

It is necessary to have a pipe two inches in diameter and about six feet long, closed at the end and with a double row of perforations on the under side, lying at the bottom of the "mooree" a few feet away from the outlet of the reservoir; the perforations should be of such a size that the sum of their cross-sections is equivalent to (or slightly larger than) the cross-section of the pipe. A cock should be attached to the pipe so that the flow of steam can be regulated; if a cock can also be fixed on the outlet from the reservoir so that the rate of flow of the water can also be regulated, so much the better. If the outlet from the reservoir is very near the end vat of the range, it may be necessary to disuse this vat since the water cannot be sufficiently heated before entering it.

Regulating and recording the temperature.

The temperature of the water should be taken in the "mooree" just over the inlet to the vat which is being supplied, and if it is too high the steam turned off a little or the rate of flow of the water increased, and *vice versa* if it is too low. The temperature should be watched at intervals during the whole time the vat is filling. It is useful to have bamboo or wooden frames standing in the vat opposite the water inlet so that the temperature of the water in the ull vat can be conveniently read (see last year's report, p. 7).

The temperature at which the water enters the vat should generally be a few degrees above that at which it is desired to steep to allow for the cooling effect of the plant and "pukka" and the drop which occurs during the steeping period, but no hard and fast rule can be laid down as to how many degrees should be allowed for this purpose. The margin must inevitably depend upon conditions; if, for instance, the plant is very wet or the air temperature very low, it will be necessary to allow more than if the plant is dry

and the air warm; but I would like to lay stress upon one point in this connection, and that is that the temperature recorded as that of steeping should be the *average* one during the whole steeping period. Thus, if it is desired to steep at 90° F., and the temperature of the water in the full vat is 93° F., it should come out at 87° F., so that 90° F. is the average over the period; and similarly if it is desired to steep at 104° F., and the temperature in the full vat is 107° F., it should come out at 101° F. I have myself found that if the natural temperature of the water is 85°-90° F. during "moorhun mahai" it is necessary to heat it to about 93° F., in order to attain an average temperature during a ten-hour steeping period of 90° F., whilst to attain an average temperature of 104° F. during a seven-hour steeping period it is necessary to put the water into the vat at about 109°-110° F.; but a larger margin is frequently required during "khoontie mahai" to allow for the lower air temperature.

Addition of alkali to the steeping-vat.

Since an efficiency of 85 per cent. can be obtained by conducting "mahai" under the conditions which have been described, it seems improbable that any further improvement will be possible in the steeping process. I have previously pointed out that all experimental results obtained so far indicate that, if ammonia (or other alkali) is used in oxidising, no substance added to the steeping vat is likely to lead to increased production; nevertheless a process having as its only essential characteristic the addition of alkali to the steeping-vat (the so-called "Glucosode" process) was introduced into Bihar this year and tried by a few planters. The few figures I have seen showing the results of the process indicate a distinctly increased outturn of finished indigo, and some analyses I have made of the indigo produced show no decrease in quality; but in no case, so far as I am aware, was the process compared with the ordinary one carried out under the optimum conditions I have laid down. A few days of "mahai" were therefore devoted to this purpose.

The results indicated that alkali is practically without effect on the efficiency if the process is conducted with ordinary (Sumatrana) plant steeping for 10 hours at 90° F., and a somewhat longer steeping given to the alkaline vat; otherwise the efficiency of the alkaline process is distinctly lower. An average efficiency of 80·8 per cent. was obtained with the ordinary process and of 82·6 per cent. with the alkaline one. The addition of alkali to the vat makes it possible, and necessary, to give a longer steeping than could otherwise be

given, no doubt due to its delaying the attainment of the acid condition in the vat and an inhibitory effect on the fermentation, but the results do not in any way justify the cost of the alkali employed (see Rawson's Report, p. 43).

The quality of the indigo made by the alkaline process was uncommonly high, averaging 78·3% indigotin, but, since the ordinary process worked on the same days and with the same plant gave indigo showing a content of 80·4% indigotin, it does not look as if the high quality was to be attributed to the use of alkali. It is an indication, however, that it has no ill-effect on quality.

I shall experiment further in this direction during next "mahai" since it is possible that, by varying the quantity of alkali added to the vat or the time of steeping, more favourable results might be obtained, or it may prove possible to attain as good results by the use of the alkali in this way as in the oxidising vat, and at a smaller cost.

Excluusion of air from the surface of the steeping-vat.

Another modification in the steeping process with which a few experiments were carried out was an outcome of some laboratory work on the indigo fermentation which is at present in progress. I had found that if an extract of the indigo plant is mixed with a solution of the enzyme and the mixture spread out in a thin layer exposed to the air, the fermentation takes an abnormal course. the production of indoxyl being considerably diminished and the enzyme being rapidly inhibited and finally destroyed; this does not occur if air is excluded from the surface. It therefore occurred to me that a similar effect might be produced at the surface of the steeping-vat and loss of indigo result. The effect of covering the surface with a layer of oil to exclude the air was therefore tried, but the results were so far unsatisfactory that the averages of the efficiencies with and without oil were practically identical, 78·2 per cent. being attained in the former case, and 76·8 per cent. in the latter. Further work in the laboratory and factory may lead to a more satisfactory result along this line.

Light loading.

Another matter to which my attention has been directed during this year has been the question of rate of loading. Several planters have shown me figures indicating that where a very light load has been given a proportionately large increase of finished indigo has been obtained, and I have myself found on one or two occasions when a vat was loaded exceptionally lightly that the efficiency of the process has been markedly high. In one case the vat was

loaded at the rate of about 99 maunds per 1,000 cubic feet, steeping carried out at 90° F. for 10 hours, and an efficiency of 90·8 per cent. obtained; and in another, loading was as light as 63 maunds per 1,000 cubic feet and steeping carried out under the same conditions and an efficiency of 94·8 per cent. attained. I have been unable to carry out a systematic series of experiments on the point, but these results seem to be an indication that it is a line worth pursuing, and I shall hope to do so at some future time. But it must be borne in mind that these figures are based on analysis of vat liquor and that with a light load losses in seet-water may be proportionately high. I think, however, planters would undoubtedly do well not to exceed the load of 120 maunds per 1,000 cubic feet recommended by Rawson (Report, p. 31).

Conclusion as regards "mahai."

However, on the whole, I am inclined to revert to my former conclusion, that if we can assure an efficiency of 85 per cent. in "mahai" we are not likely to do better. At least 5 per cent. of the available colour is inevitably left behind on the plant in the steeping-vat (see last year's report, p. 13), and the loss of the remaining 10 per cent. is hardly less than can be expected.

In this case there remains no room for improvement in "mahai" except in the subsidiary processes. It is unfortunate that the destruction of the "khoontie" crop prevented any experiments in saving losses in seet-water being carried out this year. I was unable to obtain the filtering apparatus recommended for trial for this purpose by Rawson (Report, p. 86), but hope to do so before next "mahai" and to try it alongside various methods of sedimentation.

Indigo powder.

Some progress has been made in the direction of producing indigo in powder form and its accomplishment shown a practical possibility. A machine for the purpose was devised by Mr. Briggs early in the year, and Exclusive Privilege for its manufacture granted to him (Spec. No. 292 of 1906) in October. The drawings shown on the opposite page illustrate a longitudinal section (fig. I.) and an end view (fig. II.) of the machine, and are explained as follows in the specification :—

"The apparatus illustrated consists of a drum (1) which is mounted in bearings (2) and made to revolve slowly by any suitable means, that shown consisting of a pulley (3). At each end of the drum (1) are fitted steam glands through which the inlet pipe (4) and the outlet pipe (5) pass. The inlet pipe (4) is stationary and is provided with holes (not shown) at suitable intervals to admit steam

into the drum. The outlet pipe (5) is non-rotating and is designed to remove any water from the interior of the drum formed by condensation of steam. For this purpose it is bent so as to lie close to the bottom of the interior of the drum, the lower portion (6) being provided with holes through which the water and exhaust steam pass. The end of the outlet pipe is fitted with a steam safety-valve (not shown) to regulate the pressure in the drum. Steam is admitted at sufficient pressure to maintain the drum at a temperature of 120° to 150° C.

Beneath the drum (1) is fitted a trough (7) in such a position that the drum is about half inch from the bottom of the trough. A scraper (8) is mounted just above the trough and removes the dry indigo from the surface of the drum as it rotates.

In use the indigo paste is placed in the trough and steam turned on. As soon as the drum is heated to the desired temperature it is slowly revolved in the direction of the arrow in Fig. 2 so that the indigo paste that has adhered to the drum is carried gradually round to the scraper (8) which removes it in the form of powder. A constant supply of paste is kept in the trough about two inches deep.

To prevent the indigo drying on the ends of the drum, brushes or scrapers (9) may be provided, or the ends may be insulated to keep them cool.

The apparatus may, if desired, be enclosed in a suitable covering to exclude dust, etc., and which may also assist in retaining the heat of the drum."

A machine has been made to this specification by the Bihar Iron Works and set up at Sirsiah. This machine is shown in the annexed plate. The machine was not delivered sufficiently early for experiments to be carried out with it during "moorhun mahai," and, since "khoontie mahai" failed, we have only been able to test the principles involved in its use without being able to turn out any powder in bulk. These tests have, however, proved entirely satisfactory. It has been found that "mal" dries practically instantaneously on the drum even though no pressure is attained in it, and the steam is therefore not superheated. This is an extremely satisfactory finding since it does not now appear necessary to make the drum of as great size or strength as had been contemplated, and the manufacture will therefore be cheaper.

The "mal" comes off the drum in a fine powder which on

mixing with water forms an impalpable paste quite comparable with that in which the synthetic product is supplied. The principle for removing condensed steam from the interior of the drum works well.

The experimental machine is not, however, sufficiently well made to work satisfactorily on a large scale; the method of driving by a belt is also not as good as it might be. A new machine is therefore being built by Messrs. Jessop and Co. of Calcutta, in which the drum will be smaller and the driving worked by a system of cog-wheels.

Some "mal" has been carefully sterilised and sealed up in drums with which to try the new machine as soon as it is delivered. It will probably be found necessary to make some further modifications, but I hope the machine will have been brought to perfection before next "mahai" and that we shall be then able to turn out a large proportion of our produce in powder form.

AGRICULTURE.

Introductory.

The experience of the past year has taught that in most matters connected with the agriculture of indigo (or indeed of any crop) in Bihar, it is extremely unwise to rely on experimental results obtained in any one place or any one year. The soils and cl matic conditions vary to such an enormous extent from district to district and the seasons from year to year, that any one result so obtained is apt to be very misleading. As an instance I may cite the results obtained by cutting back Java plant in the spring, to which I shall have presently to revert. My own experience at Pusa last year pointed absolutely indubitably to the practice being a good one, and I accordingly recommended it. Many planters have tried it and reported their results. These are of the most varied character ranging from those who condemn the practice utterly to those who consider it a most valuable operation and propose cutting back their whole cultivation annually as a matter of routine.

I have, therefore, as far as possible gathered my experience and based my recommendations this year on the accumulated results obtained by planters rather than on experiments carried out at Sirsiah, and have endeavoured to strike a mean in arriving at an opinion.

Any recommendations with regard to manures should undoubtedly

be based on this principle, but we have as yet so little encouraging or definite information on the subject that for the present we must be content with experiments conducted here and await their indications to provide recommendations.

Manurial Experiments.

Unfortunately the manurial experiments touched upon in my last report have failed so far to give any reliable results, and I therefore do not propose describing them in detail this year. It will be recollected that plots were made up by mixing the earth dug out of holes of uniform size and depth and returning it to the holes with the addition of the necessary manure to the top six inches. This course was pursued in order to ensure uniformity in the soil experimented with in the various plots. The results of thus disturbing and mixing the soil was to render germination of the seed sown very bad, so that resowing was necessary, and finally transplantation into the plots, before a uniform distribution of the plants could be obtained. This led to the condition of growth being very different on the various plots, and even of plants on the same plot, at any one time, so that comparisons made of the vigour of growth or the colour-content of plants derived from different plots were not reliable indications of the results of manurial treatment, age being quite as potent a factor in such matters as soil.

I had hoped to surmount this difficulty by cutting back the whole of the plant for "moorhun mahai" and comparing the results obtained from the "khoontie" plant which would then be of even growth, but unfortunately the whole experimental area was flooded in August and every plant destroyed.

Two series of analyses and leaf-content determinations were, however, carried out, the first at the end of June and the second at the end of July. Only very general conclusions can be drawn from the results. The first is that organic manure leads to the indigo plant maturing early, and a rapid decrease of colour in the leaf after maturity is attained; a well-known fact, but admirably demonstrated by these experiments. The plots are divided into two main divisions each containing 18 plots, one division received a heavy dressing of seet (in addition to the specific manures) on all the plots, the other none. The following table shows the averages of the leaf and colour-contents of the plants on each of these series as determined in June and July :—

	Seeted Series.			Unseeted Series.		
	June.	July.	Percentage difference.	June.	July.	Percentage difference.
Average percentage leaf-content ..	48·2	43·2	5	45·7	43·2	2·5
Average percentage indigotin-content in leaf ..	1·18	·59	·59	1·18	·8	·38

Thus the seeted plots had dropped 5% of leaf during the month between the two determinations, and the colour-content had gone down ·59%, whilst the plots without seet had dropped 2·5% of leaf and their average colour-content decreased by only ·38%. It is thus clearly demonstrated that the application of seet has led to more rapid "ripening" whilst it has not produced any direct increase of colour in the leaf. The leaf-content is slightly higher on the plants grown on the seeted plots at the stage of optimum "ripeness," but the rapidity with which the colour-content drops under these circumstances seems to indicate that it is unwise to grow indigo on land which has been freshly seeted.

I do not wish to suggest that this should never be done, because there are undoubtedly other benefits to be derived from seet than those connected with its effect as a plant food. It opens up the soil and conduces to aëration and it improves its moisture-holding capacity and in these ways renders the soil better able to support the plant in its young stage, but such effects are apparently equally well, or better, produced after a crop other than indigo has already been taken off the seeted land, and it would therefore seem more economical, as well as more advisable for the reason I have indicated, to do this. I believe I here reflect what is the generally accepted opinion amongst planters (see Rawson's Report, p. 12).

Another indication to be obtained from these manurial experiments is the very high indigotin-content which may be induced by manurial treatment. In one case where a plot received only calcium sulphate as manure, the content of indigotin in the leaf was as high as 1·4 per cent. in June, an increase of nearly 50% over that of the plants growing on the unmanured plots or those taken from the

general cultivation; in several other cases the colour-content in the leaf ranged between 1·2 and 1·3 per cent. These high results may, to some extent, be traced to comparatively slow growth, the plant in each case being less tall and having a higher leaf-content than the average, whilst on the plots which received the same manurial treatment with the addition of seet (so that the growth was more rapid), the colour-content in the leaf was not strikingly high. But I do not think the results can be entirely attributed to this, since under no circumstances have such high contents of indigotin been recorded before. For the present, however, they can only be taken as indications of possibilities, though as such they are of an encouraging nature.

The plots have now been cultivated and resown with Java plant; the germination this year is excellent, but it is too early to form any opinion on their comparative merits except that the seeted series is already growing well ahead of that which has received no seet.

Plant stimulants.

A second series of manurial experiments, having for their object an attempt to trace the effect of certain plant stimulants (such as salts of manganese and nickel, metallic iodides, etc.) when applied to the indigo plant in solutions of very high dilution, was started early in the year, but suffered the same fate as the first series.

Extremely dilute solutions of this nature have been found to have very beneficial effect on cereals and other crops in Japan, where extensive experiments on the subject have recently been carried out. Salts, which normally behave as plant poisons, appear to stimulate the plants to unusual growth when applied in sufficiently small doses, much in the same way as arsenic and strychnine react on the animal organism, and it is conceivable that in application to indigo a larger secretion of the colour-yielding principle or a more leafy habit might be induced. If so, the method could be applied on a large scale at quite a reasonable cost, the amounts of the substances used being so small. I shall hope to start another series of experiments along this line in the course of the coming year.

Soil inoculation.

The results of the experiments in soil inoculation have fully confirmed the opinion expressed in a special pamphlet on the subject issued by me last year, that the treatment was not likely to be of much benefit on Bihar soils. Cultures were prepared on the line recommended by Dr. Moore of the United States Department of Agriculture from nodules taken from the roots of Java indigo in January. No difficulty was encountered in obtaining the cultures,

and nodule organisms were found to possess the normal characters of *Pseudomanas radicicola.* Colonies obtained direct from the nodules consist of short, rod-like organisms of no very specific character, but on subculture into either nitrogenous or non-nitrogenous liquid media, characteristic branched forms are produced from which the identity of the organism can be at once recognised. The organism was subcultured for several generations through a series of non-nitrogenous culture tubes, and finally a large volume of culture fluid was prepared from a single tube in the manner described by Dr. Moore.

Two plots 33′ × 10′ were measured off in a field on which a very even growth of Java indigo had been obtained, the plant being about 1 foot high. A culture of bacteria was applied to one of these once a week for two months, and at the same time the other plot was given the same amount of water, in order to avoid any difference in growth due to irrigation. At the beginning of July both these plots were cut and the plant weighed with the following results :—

		M.	S.	Ch.
Inoculated Plot	..	2	24	12
Non-inoculated Plot	..	2	25	0

A closer agreement could hardly be desired, and the inoculation has clearly been without effect.

Similar experiments were carried out in the manurial series of plots, but failed to give reliable results for the reason explained above in connection with manures In a third case, seed of ordinary indigo was thoroughly inoculated with a culture of bacteria before sowing, in addition to watering the plots with a culture in the manner described above. Germination was not sufficiently even, either on the inoculated plot or the corresponding non-inoculated one, to give a reliable comparison on weighing out, but there was absolutely no difference in the vigour of growth of the plant on the two plots so far as could be judged by the eye.

The experiments clearly indicate that the soil operated on contained a sufficiency of the necessary nodule bacteria before inoculation, and that they were in a sufficiently virulent condition. I think this would certainly prove true of all the soils of Bihar.

.ion ma- . plant. The remarks made in my last report *re* the advisability of giving attention to the Sumatrana plant despite the recognised superiority and wide adoption of the Java variety, have been supported by the

experience of the past year. It seems beyond doubt that there are soils in Bihar on which the Java plant cannot be grown with advantage, in particular those heavy soils which do not permit of rapid drainage and aleration (*e.g.*, the "bhanger" soils of Chumparun). Experience has also shown that, in order to grow the Java plant with full advantage, the best period for sowing is a short one, so that the doubt expressed last year as to the possibility of preparing the whole cultivation on a large concern sufficiently early, is supported.

We have unfortunately not yet obtained the services of a botanist and have the efore not been able to undertake the systematic selection work on the Sumatrana plant which is so urgently needed. A preliminary step has been taken by growing and examining the different sub-varieties isolated by Mr. Leake in 1903. These were grown side by side in the experimental area and their leaf percentage and indigotin-content determined in July with the following results :—

Variety.	Percentage leaf-content of plant.	Percentage content of indigotin in leaf.
Multan	51·3	·825
Sukkur (Sind) ..	45·8	·757
Hissar	51	·75
Rohtak	51·5	·742
Dharwar (?) ..	46·6	·742
Meerut (?)	46·7	·725
Delhi	48·3	·705
Muzaffargarh ..	49·6	·697
Dera Gazi Khan ..	47·6	·66

Thus, on the score of leaf-content and colour-yielding power in the leaf the Multan type would seem to be by far the most desirable to establish. But there is a further consideration, that of vigour of growth and consequent yield of plant per unit area of land. In

this respect the Multan plant fell far behind the others and was, in fact, the least well grown of the whole series. The best plants were those grown from Delhi and Meerut seed, whilst those from Hissar and Rohtak seed were not only of poor growth but showed a marked tendency to early flowering, which is an undoubted disadvantage. These observations are in general accord with those of Leake, who considers that the greater vigour of growth of the plant of the Delhi class more than compensates for the higher leaf percentage of that of the Multan type.

The question of colour-content in the leaf was not taken into consideration by Leake, no method being available at the time of his observations for the accurate determination of this factor, but it would seem that the superiority of the Delhi plant is still upheld now that such determinations have been made. The height of the Multan plant at the time the analyses were performed was on an average about 3 feet, whilst that of the Delhi plant was about 4 feet, so that considering the more bushy habit of the latter variety, it would certainly not be underestimating the amount of growth of the Multan plant to put it at ¾ that of the Delhi variety. If, then, calculation is made on this reckoning, and the figures obtained by experiment for leaf and colour-content taken into account, we have as a ratio between the colour yields of the two types of plant $3 \times 51 \cdot \times 3{\cdot}825 : 4 \times 483 \times {\cdot}705$, or $126{\cdot}9 : 136{\cdot}2$—so that the Delhi plant is proportionately the more valuable.

Dasna seed-farm.

The establishment of a Sumatrana seed-farm on an extended scale at Dasna, which is in the immediate neighbourhood of Delhi, therefore seems to be a step in the right direction. Mr. Flavell, the Manager of the Dasna estate, kindly undertook the supervision of a cultivation of about 370 acres this year which will produce some 2,500 maunds of seed. The yield is not a good one as the season has been very abnormally wet in the Delhi district, but it should be the very best quality of Sumatrana seed obtainable under present conditions; it will not only be new and free from all adulteration, but it will be produced from stock which appears to possess the most desirable characters.

It is true that it may contain a certain proportion of seed other than that of the true Delhi type, due to the admixture which has taken place in past years in the various markets (see last year's report), but this possibility will be reduced to a minimum since the original stock from which the whole Dasna cultivation has been

derived was produced from seed grown locally for many generations. Further purification of the type could only be attained by careful selection, and, though this may be desirable, it must take some years to increase the selected types sufficiently to meet the demands of the whole of Bihar.

Production of Sumatrana seed in Bihar.

I pointed out in last year's report that this selection and increase of selected types could be much more efficiently carried out on seed-farms in Bihar itself than so far away as the North-West districts if the cultivation proved feasible.

Experience during this year has shown that it is not only feasible, but that there is every indication that Sumatrana seed can be grown as well in Bihar as elsewhere. Early last year seed produced at Dasna was distributed to several planters and, at my request, an area of $\frac{1}{5}$ acre was reserved from the resulting cultivation for seed purposes. Two concerns carried the matter through and sent me the seed produced, in one case 1 maund 7 seers, and in the other 1 maund 2 seers, so that seed has been produced at an average rate of 5 maunds 22 seers per acre, a yield comparing quite fairly with those obtained in the North-West.

Part of this seed was distributed amongst 6 concerns selected at points as far distant from one another and from the place where the seed had been produced as possible, and the remainder kept for experiments at Sirsiah. Ten seers were sent to each concern and the managers requested to sow this on an acre of average quality land, and to cut and weigh the produce from half the area during the manufacturing season, and to reserve the other half for seed purposes. In every case perfectly satisfactory germination was obtained, but in two instances a large portion of the crop failed from drought, and reliable cutting-out figures could not be obtained. In the remaining four cases, extremely good yields of plant seem to have been obtained, the average from the $\frac{1}{2}$ acre being 63 maunds. In each case an equal area of the general cultivation was reserved in the same or a neighbouring field and cut and weighed separately for comparison, and the average in these cases amounts to 55 maunds. The Bihar-grown seed has thus given better results despite the fact that the ordinary seed was probably sown at a somewhat higher rate.

I have not yet received the figures for the yields of seed from the remaining $\frac{1}{2}$ acre from the various concerns.

No estimate could be formed of the dye-yielding power of the

plant grown from Bihar seed on ⅛-acre plots, the plant produced being insufficient to manufacture separately. This point was determined at Sirsiah by sowing both kinds of Bihar-grown seed on 1½-acre plots, and comparing the yield of finished indigo obtained from them with that derived from plots of the same area, and in the same field, sown with ordinary open-market North-West seed and Dasna seed respectively. The plant obtained from each plot was cut, weighed, and manufactured separately, and the following results obtained :—

Variety of seed.	Yield of plant from 1½-acre plot.		Yield of 60% indigo calculated from analysis of vat liquor.	Average yield of 60% indigo per 100 maunds of plant.
	M.	S.	Seers.	Seers.
Bihar No. I. ..	170	6	23·47	13
Bihar No. II. ..	169	0	19·79	11·7
Dasna ..	239	35	24·74	10·3
Ordinary ..	126	7	19·42	15.3

These figures cannot be taken as very rigidly expressing the relative values of the different types of plant since the field on which the experiments were carried out was not of very even fertility. A large portion of the plant grown from the Dasna seed, for instance, was on a part of the field which was much richer than the rest, as is indicated both by the heavy yield of plant obtained and its comparatively poor quality. But the figures serve to indicate that no obvious drop in the quality of the plant is engendered by growing the seed in Bihar.

So far then as can be judged from seed grown for only one year in these districts, neither of the three drawbacks which I was given to understand would attach to such seed (last year's report, p. 20) appears to have shown itself. The seed germinates well, and the plant produced resists the hot-weather drought, and is generally of as good quality as that obtained from any other seed. It remains to be seen if this is upheld in succeeding generations.

Meanwhile, I would urge the formation of two or three farms for the production of Sumatrana seed on a somewhat larger scale than has been done hitherto in Bihar. I would not recommend the abolishment of the seed-farm at Dasna until some years of experience has confirmed the view that no advanatge attaches to cultivation in the North-West, but if about two-thirds of the necessary cultivation were placed at Dasna, and the remaining third distributed among three farms in Bihar, we should have an opportunity of judging of the possibilities on a wide scale, and of conveniently extending any selection which is done at Sirsiah. If it is eventually found that some actual advantage attaches to seed cultivation in the North-West districts, it will be quite a simple matter to transfer the selected varieties which have been grown on the Bihar farms to Dasna.

Sumatrana Seed-farms.

Rate of sowing Sumatrana seed.

The experiments described above for determination of the relative values of Bihar and North-West seed were made to serve a second purpose, that of comparing the effects of sowing the seed at various rates. Each of the 1½-acre plots described was divided into three equal areas and the seed sown on each at a different rate, 4, 7 and 10 seers per acre respectively. The ½-acre plots were cut, and the yield weighed separately in each case. The following results were obtained :—

Variety.	4 seers per acre.		7 seers per acre.		10 seers per acre.	
	M.	S.	M.	S.	M.	S.
Bihar I ..	67	16	55	30	47	0
Bihar II ..	73	35	45	18	49	27
Dasna ..	77	20	78	26	83	29
Ordinary ..	55	33	33	15	36	39

These figures, again, cannot be taken too rigidly because of the unevenness of the field, but there appears to be a clear indication that, except where the land is exceptionally rich (as, for instance that on which the Dasna seed was sown), advantage attaches to thin sowing. This conclusion requires confirmation, and I intend asking a few planters to collaborate with me in the matter during

the coming season. There appears to be a tendency all over Bihar to sow quite unnecessarily thickly, a custom which has doubtless arisen out of the poor quality seed which has been supplied in the past. There are, of course, many risks to be provided against before a crop is secured, and a thick germination may, perhaps, allow of some damage being done by drought or pests without making a serious difference; but with good seed, such as is now forthcoming, I would certainly not advise sowing more thickly than 8 seers per acre, and it is a question whether still thinner sowing might not be pursued with advantage.

Java plant.

It would be superfluous in this report to sound the praises of the Java plant afresh. Its superiority over the old variety is now fully recognised, and its cultivation increasing as rapidly as the available seed and its cultural requirements will permit. The past season has not been a good one to fully demonstrate this superiority, partly because it has been exceptionally favourable for the Sumatrana plant and partly because so many concerns lost their Java "khoontie" crop from floods, and it is in second cuttings that the Java plant usually so far excels the old variety; I fear, too, that understeeping and cutting back too late in the year may account for the Java plant not having done as well as might have been expected.

Nevertheless, a few figures will show that a very marked advantage has been noticeable wherever the Java cultivation has been sufficiently large to obtain comparative figures The following table summarises the returns sent in by 20 concerns who have been able to do this :—

	Average yield per acre.		Average yield per 100 maunds of plant.	
	S.	Ch.	S.	Ch.
Java plant	14	6	14	13
Sumatrana plant ..	10	15	12	4

These figures are, of course, based on cake measurement, and may probably therefore be increased by 5-10% all round in order to correspond with actual weighments, but the relation between the

results obtained with the two varieties is probably substantially correct. In our own case at Sirsiah the Java crop was very thin, and the yield of indigo per acre obtained from it does not compare favourably with that obtained from the Sumatrana plant, but, calculating on the 100 maunds, we obtained for "moorhun mahai" an average of 20 seers 8 chittacks from the former and only 17 seers 6 chittacks from the latter as determined by analysis of vat liquor and expressed as 60% indigo, or 17 seers as compared with 13 seers 2 chittacks by actual weighment; and this in spite of the fact that our Java plant was used for experimental purposes and was considerably understeeped, so that our processes were of very low efficiency as compared with those used for the Sumatrana plant (see p. 6).

Thus, even under this year's disadvantageous conditions for Java plant, it has given on the average an increase of about 35 per cent. on the area, and more than 20 per cent. on the unit weight of plant over the Sumatrana variety.

Quality of indigo made from Java plant.

As regards quality, the promise of last year seems to have been fulfilled in almost every case: the indigo made from the Java plant has generally been of higher indigotin-content, and of a better grade, as judged by the standards of the Calcutta agents, than that made from Sumatrana plant at the same factory. In our own case our average analyses for indigo made from Java plant is 68·3%, and from Sumatrana 70·5%, so that there is practically nothing to choose between them, both being of excellent quality.

Germination.

Sulphuric acid treatment of seed.

A new and improved method of surmounting the difficulty in germination attendant upon the hard coat of the Java seed was devised early in the year, and two circulars on the subject issued to members of the Bihar Planters' Association in February and September respectively. The method depends upon the application of concentrated sulphuric acid to the seed. The exact mode of action of the acid is uncertain. A somewhat detailed investigation carried out by Mr. D. L. Day and myself on the structure of the seed-coat, and the action of acid upon it, has made it clear that the hardness of the seed is associated with its possession of an extremely thin outer covering, which in some respects resembles the substance known botanically as "cuticle," and in other respects is more akin to "cellulose," which is quite impermeable to water. The action of scarifying is, no doubt, to scratch a small portion of this covering away and so allow of the penetration of water, whilst

treatment with strong sulphuric acid acts either in a similar manner by leading to the swelling of this layer and its eventual rupture, or by converting it into a body akin to cellulose and permeable to water.

An account of this research has been communicated to the "Annals of Botany" for publication. I am much indebted to Dr. E. J. Butler of Pusa for first bringing the effect of the action of sulphuric acid on "hard" seeds to my notice; it appears to have been first described by Dr. Hiltner of Berlin in 1902. In its practical application to Java indigo seed the method, as it now stands, is as follows :—

A maund of seed is placed in a water-tight wooden tub (half an ordinary kerosene barrel answers best, this gives a tub 15 inches high and 2 feet in diameter), and 5 seers of undiluted commercial sulphuric acid, such as is commonly used in the "mal" boiler, is poured over it and thoroughly mixed in with the seed with a wooden or iron instrument until every seed is wet. It is then left to stand for exactly half an hour, counting from the end of the time taken to mix the acid with the seed, which is about 5 minutes. Twenty gallons of clean cold water are then poured on to the seed rapidly, and the seed mixed round thoroughly whilst the water is added. This is most conveniently managed by having the second half of the kerosene barrel full of water alongside the tub in which the operation is being conducted, and ladling the water from one to the other with pails, unless the treatment can be conducted in the mmediate proximity of a tank or other source of water; twenty gallons will very nearly fill the tub. It is very important that the water be added rapidly and the stirring be thorough; there should be only a very slight rise in the temperature of the water on adding it to the acid. The diluted acid can be stirred with the hand without danger.

When thoroughly stirred the tub is left standing for a few seconds, during which all the good seed will sink to the bottom, whilst a large portion of the bad seed and impurities will float up and can be poured off with the water with no risk of loss of anything of value. As much fresh water is now added and the washing repeated exactly as before, the water with the suspended impurities is again poured off and a third lot of water added. This operation is repeated until the seed is practically free from acid. About six washings are required to attain this end, which can be recognised

by tasting a small portion of the seed; it should taste hardly appreciably acid.

After the last lot of water has been poured off, the seed is removed from the tub and placed on a sieve such as is used for straining indigo "mal," and left for a few minutes to drain. It is then spread out on sheets to dry. The drying should proceed as rapidly as possible, and it is therefore best to select a dry, sunny day with a west wind blowing, and to turn the seed over at intervals whilst it is progressing. It is frequently found difficult to select a sufficiently settled day during the season when the treatment is carried out (the end of the rains), and the drying should therefore be conducted in the neighbourhood of a shed or verandah, so that the sheet with its contents can be carried in and put under cover if a shower of rain comes on. The drying can be quite satisfactorily concluded under cover, even if it be raining outside, if the seed is constantly turned over. When dry, the seed is ready to sow.

Good seed treated in this way has been found to germinate 100%. It should never be less than 90% germination capacity if the operation is properly conducted and the seed is good. The treatment costs about Re. 1 per maund, varying with the cost of freight on the acid, and can be carried out at the rate of 4 maunds an hour with 4 tubs and a water-supply at hand. The method has been very carefully tested both here and by many planters, and invariably with satisfactory results. It requires a little care, but if the above directions are strictly adhered to, and a certain amount of caution is exercised in handling the strong acid, no difficulty should attach to it. If it is properly carried out, and the sample of seed dealt with is a good one, which does not contain a large proportion of unripe seeds, there should be very little loss of seed indeed. If there are many unripe seeds, a large proportion of them will split up under the treatment and be washed away, but their elimination will be an advantage in the long run. It may generally be taken that a sample, which contains a large proportion of seeds, which split under treatment, is a bad one, the presence of many unripe seeds pointing to imperfect development of the whole sample.

This method of treatment has many advantages over mechanical scarifying.

In the first place, it is much more certain in action, since definite rules can be laid down and no mechanical adjustments or devices are necessary in order to deal with seed of varying sizes.

There is thus no risk of crushing seed or of seed escaping treatment.

Secondly, the process eliminates a very large proportion of split, hollow, and unripe seeds, as well as other impurities, and so improves the value of the sample operated on by exercising a sort of preliminary selective action.

Thirdly, the germination of seed so treated is much more rapid and more regular than that of seed mechanically scarified, which is of very great advantage in tending to produce a thick crop all over a field at one time, and so minimising risks of attack from pests.

Lastly, the appearance of the seed is very much improved, the surface being rendered smooth and glossy instead of becoming rough and dusty, as is the case after mechanical scarification.

I would strongly recommend this method of treating seed to planters, and would take the opportunity of repeating the caution given in last year's report as to not sowing untreated seed, or seed whose germination capacity has not been satisfactorily tested.

Sowing.

There are two main questions connected with sowing on which some knowledge has been gained during the year. Firstly, as to the time of sowing, and, secondly, as to the method of so doing. There can no longer be any doubt that October is, under ordinary circumstances, the best month during which to sow. Exceptional conditions, such as a severe visitation of grasshoppers, which occurred in Sarun this year, during October, may occasionally render it advisable to postpone sowing until later, but all experience points to the moisture and temperature conditions being generally at their best for the germination of the Java seed during this month. The Java plant is a slow-growing one and distinct advantage attaches therefore to sowing early, so that it may have as long a time as possible to develope before it is cut for "mahai," or is pruned in the spring. For this reason February and March sowings are not to be recommended. Germination may sometimes be secured, and it is likely that acid-treatment of the seed will render the probability greater, but the plant has not time to develope fully by the manufacturing season, so that it must either be cut very small or left very late, and a second cutting, if obtained at all, is bound to be delayed until October, or later, by which time the weather has become cold and the colour-content of the leaf consequently lessened. I may cite in support of this some figures returned by a factory, where the plant derived from October

and February sowings, respectively, was manufactured separately; it is estimated that the October sowings gave, on an average, 11 seers, and the February sowings 5 seers of finished indigo per bigha for "moorhun mahai," whilst the former gave 6 seers 9 chittacks and the latter 2 seers 12 chittacks for "khoontie mahai." Similar experience has, I believe, been general.

As regards the mode of sowing, the choice lies between drilling the seed or broadcasting on land prepared with the "gallien" and rake. Decision on a matter of this kind must depend upon local conditions and upon season, and no hard and fast rule can possibly be laid down. In some cases, for instance, broadcasting proved the better method last year and drilling has been more satisfactory this, possibly due to the fact that last year was one of good moisture and this year it is short, so that the deeper sowing of the drill was a disadvantage in the former case and an advantage in the latter. In our own case at Sirsiah, this year, it is impossible to detect the least difference between the results obtained by the two methods. I do not think any harm can possibly attach to sowing with the drill, provided it is adjusted to sow the seed only just sufficiently deep to be within the moisture layer, and, undoubtedly, the advantage rests with this method if moisture is short, and on the score of more uniform germination; but, on the other hand, if time is an object, and it is a question of sowing partly broadcast or delaying sowing until late in the year, it would seem that, under normal moisture conditions in October, the latter method can be pursued quite satisfactorily.

A possible advantage of sowing the seed in drills is that cultivation of "khoonties" is rendered somewhat easier, owing to the more regular distribution of the plant; but it is an open question whether any benefit is derived from this cultivation, and many planters consider that it is a distinct disadvantage. It would seem that thorough weeding and the consequent hoeing between the plants is all that is necessary; but further experience is needed on this point.

As regards rate of sowing, I am still of the opinion that five seers per acre is the amount to be recommended—more than this is wasteful, less is apt to lead to too thin a crop to allow for the probable death of a certain percentage of plants before the second cutting is taken in the second year.

I have previously mentioned that the utmost variety of opinion

Cutting back in the spring. exists as to the value of cutting back the young Java plant in the spring. The general view expressed against the practice is that it sets the plant back to such an extent that it does not recover in time for satisfactory manufacture at the usual season; and that in favour of it is a reflection of my statement in this connection in last year's report, *viz.*, that it leads to a very much thicker crop and a much larger leaf-content in the plant at the manufacturing season.

The conclusions to be drawn from the consensus of opinion, and my own experience, seem to be as follows:—

I. Cutting back is not likely to be of marked value in a thick crop.

II. It should never be done later than February.

III. It should never be done on plant less than a foot high, and this will only generally be attained in February by plant sown in October.

IV. In a thin crop, and on reasonably good soil, it is likely to be of the utmost value.

I think the disappointment experienced this year by many planters, in connection with this matter, was mainly due to cutting back too late in the year and, in some cases, to cutting too close to the ground, at least 3—4 inches of stem should be left to give rise to the new shoots.

Manufacturing spring cuttings. An experiment in manufacturing from the spring cuttings of Java plant was carried out at Sirsiah in March last. Two neighbouring factories kindly supplied me with cuttings for the purpose, our own cultivation being too backward to cut. The plant had to come a considerable distance, and, owing both to this and to the closeness with which the small plant packed on the carts, as well as the long time required to collect a cart load, it was considerably heated and burnt before arrival. The plant was very leafy, its average leaf content being 64 per cent., and the average content of indigotin in the leaf was ·57 per cent. Seventy-five maunds of cuttings were collected and this was steeped at 90° F. for 10 hours. The yield of indigo obtained, calculated from analysis of vat liquor and expressed as 60 per cent. indigo, was 3 seers 6 chitacks, a very poor yield and an indicated efficiency of only just over 20 per cent., a result probably to be accounted for by the large proportion of burnt plant. The quality of the indigo produced was also excessively poor, and showed, on

analysis, only 29·7 per cent. indigotin, and contained a very large amount of yellow colouring matter.

The general conclusion to be drawn from this experiment is that it is hardly likely to be worth while manufacturing from the spring cuttings of first year plant, unless the cultivation is very large, the plant very advanced, and some contrivance such as a mechanical reaper could be used to cut and gather the plant quickly; even in this case, the quality of the indigo obtained would probably be poor. The best thing to do with the cuttings would seem to be to put them on to the seet-heap or to bury them in the field from which they are cut, and, when rotted, dig them up for manure. It might be unwise to leave the cuttings lying about on the fields, since they may become harbouring places for insect pests.

It may prove profitable to manufacture from shoots cut from second year plant early in the year, since a greater bulk of these can be obtained from a smaller area, and it is of undoubted advantage to the plant to remove them.

Number of years during which the Java plant can be used for manufacture.

I was enabled to obtain some data on this head by the kindness of Mr. F. Coventry of Dalsing Serai, who allowed me to analyse a number of samples of Java plant growing in his "dehât" in July last. First, second, third, and fourth year plant was to be found growing in adjacent fields, and a series of leaf and colour determinations were made of each. The following figures show averages of the results obtained :—

Age of plant.	Leaf-content.	Colour-content of leaf.
1st year	48 %	·844 %
2nd year	41·2 %	·914 %
3rd year	47·7 %	·631 %
4th year	36 %	·843 %

Probably these results are more influenced by the peculiarities of the particular plants analysed, or of the soil on which they were growing, than by age, since no regularity exists among them, but they serve to show that no very marked decrease in colour or leaf-content takes place even after years. The appearance of the

fields was very different however. Those on which first and second year plant was growing seemed to carry a full crop and to promise a very good cutting, the second year plant looking quite as good, if not somewhat better, than the first year ; but the fields containing third and fourth year plant bore very straggly and scattered crops, and so many plants had died out that the remainder seemed hardly worth keeping. The general impression gained was that, although the quality of the plant may be upheld during the third and fourth years of its growth, the strain on the land is likely to be so severe that it is not advisable to keep it more than two years. A conclusion of this sort, however, requires considerable confirmation, and the issue is likely to be considerably affected by peculiarities of soil and season.

Java seed-farms.

The question of Java seed supply has been much debated during the past year, and although the Bihar seed-farms are now an accomplished fact, there is, I believe, a section of the planting community which considers that the cultivation of seed in Bihar is likely to lead to degeneration of the stock. It has been suggested as an alternative that a seed farm should be established in Natal from which the stock may be kept up from time to time.

The reason commonly given for anticipating this degeneration is one of analogy. The Sumatrana indigo plant, the common native "râbi" crops, the flower and vegetable seeds of our gardens, are severally pointed to as indicative of degeneration in Bihar, and the conclusion is drawn that, if these have degenerated, why not Java indigo ?

Now in each of these cases a very satisfactory reason for degeneration can be found without falling back upon any one connected with climate. In the case of Sumatrana indigo the explanation—no doubt a correct one—has been often given that the degeneration is almost entirely to be traced to admixture of the seed of inferior sub-varieties with those of Delhi and Cawnpore in years when the seed supply was short in the North-West districts. In the other cases degeneration may be very largely traced to the lack of any system of exchange of seed from district to district, or from garden to garden. Precisely similar degeneration takes place in any climate if seed is continually sown in the place it has been produced, but an exchange of seed over a distance of 50 miles is frequently more efficacious than one over 500 miles, and it is not to be ascribed to any violent change of climate. It is in fact true that

a change of this latter sort frequently gives rise to ill-effects, but there is absolutely no evidence to lead us to suppose that this has occurred, or will occur, as an outcome of the introduction of Java indigo into Bihar; on the contrary, the vigour with which the plant grows, and more especially the readiness with which it flowers and produces seed, are indications that it is admirably fitted to the Bihar climate, and that nothing but judicious cultivation and exchange of seed from district to district is necessary to uphold its condition.

I was given an opportunity of obtaining some figures bearing on this point by the kindness of Mr. F. Coventry of Dalsing Serai. Mr. Coventry had sown plots of three kinds of seed in a field near his factory, seed freshly imported from Java, and seed derived from plant grown for three generations in his own concern from Java and Natal plants respectively. In July last I examined these plants and obtained the following results :—

Seed from which plant was derived.	Average percentage leaf-content.	Average percentage content of indigotin in leaf.
Freshly imported Java ..	54	·794
3rd generation Java ..	48	·844
3rd generation Natal ..	46	·701

Thus, so far as three generations are concerned, there is no indication whatever of degeneration, and this notwithstanding the fact that no exchange of seed has been exercised.

It is, of course, possible that in the course of years some signs of degeneration will show themselves, but I do not see any ground for considering this probable, if proper regard to the system of cultivation and exchange of seeds is continued. If it does occur it will not happen suddenly, and, if attention is continuously paid to the matter, there will be ample time to consider the advisability of starting seed-farms in other countries when an indication of its approach is obtained.

The above figures seem to clearly indicate that, in the event of this contingency arising, Natal will not be the place to start a farm. It is clear that the superiority of the plant obtained from

Java seed over that obtained from Natal seed, which is so evident when the plants from freshly imported seeds from these countries are compared (see last year's report, p. 29), is upheld into the third generation, and there is no reason to suppose that it will be diminished in succeeding ones. The place to start a farm, in the event of any foreign one becoming necessary, would therefore seem to be Java rather than Natal.

In accordance with my last year's suggestion, farms for the cultivation of Java indigo seed were started at three places in Bihar last March. The situations of the farms have been selected as far distant from one another as possible, and the seed they produce will be distributed to concerns as remote from the supplying farm as can be arranged. It was necessary to start the farms with plant already growing on the lands belonging to the concerns in which they are situated, since the sowing season had passed and the only selection which was possible was to pick fields in which the plant seemed to show the strongest growth. Thanks are due to the managers of the three farms for allowing and assisting in this, and for the attention they have paid to the cultivation on the seed-farm areas. The plants were not cut back at all, and were thinned out to 1½′ apart. It remains to be seen if this is the best distance apart at which to leave the plants; failing more exact knowledge it seemed a safe one to adopt with a view to giving each plant sufficient room without risking too heavy a decrease in yield. A series of experiments bearing on the point is now in progress at Sirsiah, but the results are not yet obtained. The procedure for next year's crops on the seed-farms will be guided by the results of these experiments.

All the seed at the farms will be hand-picked as it ripens, as far as possible, but I have asked each manager to reserve an area to be cut and thrashed separately without hand-picking in order to determine precisely how much value attaches to the practice.

The crops for next year have just been sown on the farms, the seed used being carefully selected "moorhun" produce from sources as distant as possible from the farm supplied. The seed was all treated with acid at Sirsiah, and germination is generally excellent.

Some doubt appears to exist as to the benefit to be derived by obtaining Java seed from the farms, and a few words of explanation would perhaps not be out of place here. It is not claimed that

anything which is being done at the seed-farms could not equally well be done by planters themselves, since, at present, no scientific selection is being attempted. This may, and should, be done at some future time, as the Java plant is undoubtedly a mixture of many varieties, but for the present the only advantage, except careful cultivation, which attaches to seed produced on the farms, is that the principle of growing only "moorhun" seed and of ensuring change of environment between place of production and sowing are being carefully safeguarded.

The seed-farms have been established partly because of the doubt of these principles being fully borne in mind by planters and partly as providing convenient distributing centres.

The advantages of "moorhun" seed are not easy to demonstrate by practical experience since very little has been in circulation in Bihar hitherto, but it must surely be obvious that a well-developed parent is most likely to give rise to well-developed offspring, and, as a matter of fact, comparison of "moorhun" and "khoontie" seed by any standard which is ordinarily applied in judging of the quality of seed will invariably declare in favour of the former. Such standards of quality are (i) germination capacity; (ii) germination energy; (iii) weight; (iv) form. As regards germination capacity the case of Java indigo seed is a very special one, since properly ripened seed will not germinate at all without special treatment; but this very fact provides us with a valuable test of the quality of a sample, as any seeds present which are not fully ripened will germinate without treatment, though the plants they produce are poor weakly ones which would probably die out at an early age and would certainly never develope into hardy stock. There is generally a much larger proportion of such seeds in "khoontie" samples than in "moorhun" ones, presumably due to the shortening of the developing and ripening stages in the former case; in one sample I have examined I found as many 21% of the seeds germinated without treatment! After treatment with acid the germination capacity of the two types of seed will probably be equally good, since a large proportion of the unripe seeds are eliminated from the "khoontie" sample; but the "germination energy" is very different. By this term is meant the rate of germination and the size and vigour of the shoot which is extruded. In both these matters "moorhun" seed shows a marked superiority, the seeds germinate more quickly and the

shoots are well developed and well beset with fine root-hairs. Again in the matter of weight, "moorhun" seed has the advantage. In some comparative weighments I have made of 100 seeds of each type, the "moorhun" showed an increase of about 10% over the "khoontie," but I am inclined to think my samples were not very typical, and that an even greater difference could be shown in some cases. The relative sizes of the two types of seed is, of course, proportional to their relative weights. Finally, with regard to form, all the advantage rests with the "moorhun" seed. It is invariably larger and more shapely, and the colour more uniform, and a well-ripened sample contains extremely few of the shrunken, half-formed seeds characteristic of "khoontie" samples.

All these are indications that the "moorhun" seed will produce a stronger and hardier plant, more able to withstand adverse conditions, and more likely to develope into a well-grown adult. A very good demonstration of this has been obtained on the seed-farm at Rajpore this year. All the farm fields which were sown with "moorhun" seed show perfect germination and remarkably rapid and hardy growth for the first two months of the plants' development, whilst fields alongside sown for "mahai" purposes with "khoontie" seed, treated in the same way and sown in the same way and at the same time as the seed-farm fields, carry a remarkably poor crop due to the plants having succumbed to the heat during October and November or to the attack of grass-hoppers. This difference cannot be traced to any other cause than that of the employment of "moorhun" seed in the one case, and "khoontie" seed in the other.

I may perhaps be permitted to give some quotations from some authorities on the question of seed-production in connection with the matter discussed in the last few paragraphs. The following extract, dealing with the question of change of seed, is taken from Prof. Bailey's book, "Plant-Breeding":—

"Almost every farmer and gardener at the present day feels that an occasional change of seed results in better crops, and there are definite records to show that such is often the case. In fact, I am convinced that much of the rapid improvement in fruits and vegetables in recent years is due to the practice of buying plants and seeds so largely of dealers, by means of which the stock is often changed. Even a slight change, as between farms of neighbouring villages, sometimes produces marked results, such as more vigorous

plants and often more fruitful ones. We must not suppose, however, that because a small change gives a good result, a violent or very pronounced change gives a better one. There are many facts on record to show that great changes often profoundly influence plants, and when such influence results in lessened vigour or lessened productiveness, we call it an injurious one. Now, this injurious influence may result even when all conditions in the new place are favourable to the health and development of the plant; it is an influence which is wholly independent, as far as we can see, of any condition which interferes injuriously with the simple processes of growth.''

And again, dealing with the question of selection of seed, the same authority writes :—

''Better results usually follow the sowing of large and heavy seeds than of small or unselected seeds from the same plant . . . The good results which follow the use of large seeds are, chiefly, greater uniformity of crop, increased vigour, often a gain in earliness and sometimes in bulk, and generally a greater capacity for the production of seeds. These results are probably associated less with any innate hereditable tendencies than with the mere vegetative strength and uniformness of the large seeds. The large seeds usually germinate more quickly than the small ones, provided both are equally mature, and they push the plantlet on more vigorously. This initial gain, coming at the most critical time in the life of the new individual, is no doubt responsible for very much of the result which follows. The uniformity of crop is the most important advantage which comes of the use of large seeds, and this is obviously the result of the elimination of all seeds of varying degrees of maturity, of incomplete growth and formation, and of low vitality. Another important consideration, touching the selection of seeds, is the fact that very immature seeds give a feeble but precocious progeny . . . They germinate readily but the plantlets lack constitutional vigour and are more easily affected by retarding or harmful influences . . . These characters will be more strongly emphasized in subsequent years by continuous seed propagation.''

The following extracts are taken from Percival's ''Agricultural Botany'':—

''Well-ripened seeds usually germinate more rapidly than those imperfectly ripened, but the reverse is the case in some instances,

especially if the trials are made soon after harvesting the seed. Immature seeds, however, produce weak plants, and if kept, lose the germinating-power sooner than well-grown ones." This is true of unripe Java indigo seeds (see p. 40).

"Apart from theoretical considerations, it has been shown by a large number of experimenters that, leaving out the very large ones as exceptional, and to some extent probably diseased, the larger the seed the more vigorous the embryo plant, and the more food it possesses for its early development. The larger root, which it generally has, enables it to become more easily established in the ground, and it is better able to carry on "assimilation" on account of its superior leaf-surface than a plant from a smaller seed. The vitality of plants raised from small seeds is not so great as from larger ones; they are more liable to succumb to adverse conditions of climate and soil. It has been shown that the amount of produce given by the use of large seeds is greater than that obtained when smaller ones are employed; moreover the quality, so far as size is concerned, is generally transmitted from parent to offspring, large seeds giving large, and small seeds giving small plants."

Harvesting Java indigo seed.

Since I started writing this report, I have had some queries as to the best method of harvesting Java seed, and therefore include a paragraph on the subject. There is not much to be added to my circular on this matter issued in December last. Hand-picking is undoubtedly the soundest method to pursue, but I would not recommend every pod being plucked as it ripens, unless the plants are very far apart, since there is a liability of more harm than good being done by coolies constantly at work in the fields breaking branches and generally damaging the crop. The better plan would seem to be to wait until a fair proportion of the seed is ripe and then either strip off the ripe pods or cut the branches bearing them, to then wait a few weeks and repeat the operation, and so on, until only a small proportion of seed remains at the top of the plants, which will ripen fairly evenly. If the crop is not too thick it will be possible to pluck the seed in this way, even if the plants are very tall, by pulling the branches down. If plucking is impossible, the only alternative course is to wait until the maximum amount of seed has ripened and the minimum has dropped, and to cut the whole plant down. The quantity obtained in this way will probably not be so much less than that obtained by hand-plucking as to justify the cost of this operation, especially if the seed, which has fallen,

is gathered off the ground; but the quality is bound to be inferior since there will be a large proportion of unripe or half-ripe seeds in the sample. In gathering the seed, care should be taken to eliminate any weeds or foreign varieties (*e.g.*, the Madagascar plant mentioned in last year's report, p. 28).

The seed is thrashed out and treated like any other seed crop (*e.g.*, mustard). Mechanical winnowing will, no doubt, considerably improve the quality of the sample by removing dirt and many impurities.

After as much seed as possible has been gathered, the plants should be cut down to within about 4 inches of the ground. The best instrument for this purpose is the large size "Myticuttah," sold by Messrs. T. E. Thomson and Co. of Calcutta. These instruments do excellent work, cutting through the thickest stem with great ease and without disturbing the roots in the slightest degree. They cost Rs. 7-8 a piece, and half a dozen or so will prove a very profitable investment. Failing this instrument, a sharp knife should be used; I am inclned to think the "sawing" action of the "haswa" is liable to do considerable damage to the plant.

After the crop is cut the land may be "tumnied" or ploughed between the plants, but probably a thorough weeding is all that is necessary, and is to be recommended by preference as avoiding any risk of injury to surface roots.

Storing Java indigo seed.

I have had several queries in the course of the year as to the best method of storing Java seed, and have carried out some experiments on the point.

Portions of two samples of seed, one treated with acid and the other untreated, were closed up in air-tight bottles all through the rains, and at the same time other portions were spread out in boxes exposed to the full effect of the damp air; samples of the untreated seed were also put in a canvas bag hung in the air, and in a canvas bag buried in "bhoosa" respectively. The untreated sample showed a germination capacity of 21% without treatment (showing that it contained that proportion of unripe seeds), and of 90% after treatment with acid, before the rains. The treated samples showed a germination capacity of 84% at the same time.

On testing the various samples after the rains, the following germination capacities were obtained :—

Kind of seed.	Method of storing.	Germination capacity.
Treated seed.	Closed bottle ..	84%
	Open box ..	Nil.
Untreated seed ..	Closed bottle ..	8 % without treatment. 90 % after treatment
	Canvas bag ..	74 % after treatment.
	Bhoosa ..	77 % after treatment.
	Open box ..	60 % after treatment.

These results show :—

I. Treated seed can only be kept over the rains in sealed vessels.

II. Untreated seed can be kept in dry sacks with safety.

The loss of about 15 % in germination capacity which the untreated sample, stored in a sack, appears to show, represents a proportion of the unripe seeds in the sample. It will be noted that the germination capacity of this sample without treatment, has gone down from 21% to 8% (even when kept in a closed bottle) after storage, indicating the death of nearly 50% of the unripe seeds, or 13% of the whole sample. This accounts for the greater part of the drop from 90% to 75% in the germination capacity of this sample after treatment, which took place during the storage period and would not have occurred if the sample had been fully ripened. It was a sample of '' khoontie '' seed.

Java seed should then be kept in an untreated condition over the rains, and be stored in dry sacks in a dry house and kept off the ground. It may be kept in a treated condition during the dry months without risk since the harm arises, not directly from the treatment, but from the fact that the protective coating is removed and the seed suffers from the attack of moulds.

Early in the year some samples of indigo seed, which had been selected by the late Mr. Gollan at the Saharanpur Botanic Garden, were sent to me by Mr. F. Murray, and were sown here. The plants obtained from the various seeds were analysed and the results have been recorded, but they do not appear to show any peculiarity, and none of the samples appear to represent distinct types. The seed from the different plots has been again kept separate and may serve as a nucleus for some future selection work. **Other Experiments.**

Several species of *Indigofera* were grown and analysed during the year, and last year's results in connection with the leaf and indigotin-content of *I. longiracemosa*, *I. anil*, and *I. oligosperma*, confirmed.

Cuttings of another indigo-yielding plant (*Strobilanthes flacidifolius*) were obtained and planted in the experimental area, but were destroyed by floods. I hope to grow this plant and some others which yield inidgo during the coming year and examine them.

In conclusion, I wish to record my thanks to the many planters who have materially assisted me by carrying out experiments and sending me results, and to the members of the Sirsiah staff. **Conclusion.**

REPORT

OF THE

INDIGO RESEARCH STATION, SIRSIAH,

(*Under subsidy from the Government of Bengal.*)

FOR THE YEAR 1907–1908

BY

CYRIL BERGTHEIL.

The following scientific papers on Indigo have been published during the year :— **Scientific Papers.**

"Analysis of Indigo." Part II, by I. Q. Orchardson, B.Sc.; S. H. Wood, B.Sc., and W. P. Bloxam, B.Sc.—*Journal of the Society of Chemical Industry*, Vol. XXVI, p. 4.

"The Determination of Indigotin in Commercial Indigo," by Cyril Bergtheil and R. V. Briggs—*Journal of the Society of Chemical Industry*, Vol. XXVI, p. 182.

"Some Constituents of Natural Indigo," Part I, by Arthur George Perkin and W. Popplewell Bloxam—*Journal of the Chemical Society*, Vol. XCI, p. 279.

"Constituents of Natural Indigo," Part II, by Arthur George Perkin —*Journal of the Chemical Society*, Vol. XCI, p. 435.

"Indican," Part I, by Arthur George Perkin and William Popplewell Bloxam—*Journal of the Chemical Society*, Vol. XCI, p. 1715.

"The Determination of Indigotin in Indigo-yielding Plants," by Cyril Bergtheil and R. V. Briggs—*Journal of the Society of Chemical Industry*, Vol. XXVI, p. 1172.

"Analysis of Indigo (Part III) and of the dried leaves of Indigofera Arrecta and Indigofera Sumatrana," by R. Gaunt, Ph.D. (Berlin), M.Sc. (Leeds), F. Thomas, B.Sc. (Manc.); and W. P. Bloxam, B.Sc. (Lond.)—*Journal of the Society of Chemical Industry*, Vol. XXVI, p. 1174.

The majority of these come from Leeds University where Mr. Bloxam has been continuing his researches. He holds as an outcome of these that there is further room for improvement in the process of indigo manufacture to the extent of some 60 per cent. I am obliged to disagree with this contention, and my grounds for so doing will be found in my past reports and in the papers mentioned above by Mr. Briggs and myself.

A practical dye-test of synthetic *v.* natural indigo was carried out early in the year at the Cawnpore Woollen Mills, who very kindly lent two vats for the purpose and rendered very valuable assistance in other ways. A full account of this test was published and circulated to all members of the Association in February last, so that it is un necessary to recapitulate the details here. The practical outcome was that, in vats made up to contain equal quantities of indigotin in the unit volume of liquor, natural indigo was found to give very **Dye-tests.**

much better dyeings than synthetic, and this in three successive dips of pieces each 50 yards long in each vat.

The account of the test was issued with some reluctance, since it was felt that such unexpected results required confirmation before any definite conclusion could be drawn from them; but, since such confirmation could not be forthcoming until a dye-house was fitted up and other necessary preparations made here, it was decided to publish the account for what it was worth. Its appearance led to some critical correspondence, and some weight must be attached to the criticisms which have been advanced.

In a recent number of the Indian Trade Journal (Sept. 5th, 1907) an explanation of the results of the test is offered by Messrs. Ostermayer & Co., the Badische Anilin and Soda Fabrik's agents in Bombay. It is pointed out that the brand of synthetic indigo paste which was supplied for the test was their brand "E," which contains, besides indigotin, water, and "fermentable matter," some 25 per cent. of caustic lime, and that the presence of this alkaline material in the paste would in itself account for the poor results obtained by its use in the hydrosulphite vat. There can be no doubt that, to some extent at any rate, this explanation is a correct one; the paste did certainly contain lime, and an excess of this substance in the synthetic vat would certainly lead to poor results. It is, therefore, very unfortunate that this particular brand of paste was supplied for the test, for though I was aware that it contained other substances than indigotin and water (see account of the test, p. 2), my object was to carry out the test in an absolutely practical way, basing my quantities on indigotin-content only, and the conclusion I drew was such as would have been, and in fact was, drawn by any practical dyer under the same circumstances.

It is impossible to say what might have been the result had I used some other brand of synthetic indigo, and it is still an open question whether the *whole* of the inferior effect obtained with it is to be explained by the composition of the paste. We have still to contend with the confirmed opinion of many dyers of lifelong experience that natural indigo does indeed give superior results under equal conditions of working. I have not yet had the opportunity of taking the matter up again, since our dye-house was only just complete before the manufacturing season commenced. I hope, however, to do so very shortly. We shall, of course, avoid synthetic paste "E" in future experiments and make use of the brand which the Badische's agents themselves recommend for use in hydrosulphite vats.

Laboratory work.

Accounts of work which is now in progress in the laboratory will be published in due course. A large number of indigo analyses

and seed tests have been carried out for planters in the course of the year, and these, together with the work involved in controlling manufacturing experiments, now form a large proportion of the laboratory routine.

MANUFACTURE.

Introductory. The manufacturing season was divided into four sections. A week in June (13th to the 21st) was devoted to steeping experiments with the more advanced Java crop. The main "moorhun mahai" (July 30th to August 29th) was occupied with further experiments of the same kind, with trials of alkalis and alkaline mixtures in the steeping-vat, and with experiments on rates of loading. "Khoontie mahai" was short and the growth of the plant very unsatisfactory owing to the lack of rain; it was devoted mainly to tests of the seet-water filtering apparatus. Finally a few days' manufacture was carried out in December with some third cuttings of the Java crop, in order to determine what success could be expected at this late season if proper precautions were taken with regard to heating the water.

Steeping Java Plant. It will be remembered that, in last year's report, I was unable to give any advice founded on a sufficiency of experiments with regard to the steeping of the Java plant. I recommended tentatively, however, that 12—13 hours at 90° F. and 8 hours at 104° F. should be adopted The former set of conditions was tried during the first "mahai," and it was found that a very low efficiency was attained both at 12 and 13 hours, although the yield of indigo was good (averaging, by analysis of vat liquor and calculation, as 60% indigo, 18 seers per 100 maunds of plant at 12 hours, and 25 seers 6 chittacks at 13 hours). Longer periods of steeping were accordingly tried with the following results :—

13	hours' steeping	=	57·7%	efficiency.
14	,, ,,	=	68·4 ,,	,,
15	,, ,,	=	71·4 ,,	,,
16	,, ,,	=	64 ,,	,,

Thus 15 hours' steeping at 90° F. has given the most efficient process. It will be seen subsequently, however, that this long steeping was not found necessary later in the year, and the necessity no doubt arose due to the very rich plant dealt with. The plant used for the 12 and 13 hour experiments contained as much as 1·2% of indigotin in the leaf, and the average content during the whole of the first "mahai" was 1% whilst the average leaf percentage of the plant was 43. This high colour-content is characteristic of plant cut before the break of the rains, and such plant therefore requires special steeping condi-

tions (see later under "General Rule for Steeping"). Probably a more efficient process than that obtained by steeping for 15 hours at 90° F. might be arrived at by employing a higher temperature, but opportunity did not occur for testing this point with this particular class of plant.

These experiments were repeated during August, and it was then found that, the colour-content of the plant having dropped to the normal (about 0·7% on the leaf), the steeping period recommended in last year's report did indeed give the best results at 90° F. The following average results were obtained :—

12	hours' steeping	=	81·2%	efficiency.
13	,, ,,	=	87·1 ,,	,,
14	,, ,,	=	74·5 ,,	,,
15	,, ,,	=	73·5 ,,	,,

Thus 13 hours at 90° F. gives as efficient a process with plant of this class as can be desired.

Experiments were also carried out in steeping at 104° F. with the following average results :—

7	hours' steeping	=	85·3%	efficiency.
8	,, ,,	=	89·3 ,,	,,
9	,, ,,	=	84·1 ,,	,,
10	,, ,,	=	77·2 ,,	,,

Eight hours at 104° F. has thus also given a process of very high efficiency, but it is doubtful if the slight advance on the result obtained by steeping for 13 hours at 90° F. is constant enough, or large enough, to justify the extra heating of the water.

Steeping Sumatrana plant.

A few days were devoted to a repetition of the experiments described in past reports on steeping the Sumatrana plant at 90° F. It will be remembered that hitherto 10 hours' steeping has been found to give optimum results. It was now found that 10½ and 11 hours gave slightly better results than 10 hours, whilst 11½ hours was too long. The optimum period for steeping the Sumatrana plant must, therefore, be placed at 10—11 hours rather than rigidly at 10 hours, and the exact period must be adjusted according to the quality of the plant; 10½ hours is probably as near an approach as can be made to the period which represents average conditions. There is no doubt that the difference in the results obtained this year is due to the superior quality of the plant employed, and it is another indication of how difficult it is to lay down a hard and fast rule in matters of steeping, even if due regard be taken of temperature, unless the plant can be previously analysed.

Steeping Times!

General Rule for Steeping.

For this reason I wish it to be clearly understood that, in the following table in which I have endeavoured to give, as a result of the past three seasons' experience, a general rule for steeping both kinds of plant, the periods of time given apply to :—

(*a*) Plant in *average* condition. That is to say to plant cut after the rains have set in, and before the cold weather has begun from land which is in fair heart, and has not been subject to any exceptional condition such as flooding.

(*b*) Vats not loaded more heavily than 120 maunds per 1,000 cub. feet.

The periods given should be made half an hour longer in dealing with plant which is exceptionally leafy or is judged to be exceptionally rich in colour-yielding material for any other reason ; or, conversely, half an hour shorter if the plant is exceptionally "sticky" or otherwise of poor quality. Plant cut before the break of the rains should be given two hours' extra steeping at 90°, and a proportionately smaller increase at the higher temperature. Under no circumstances should steeping be carried out at a lower temperature than 90° F.

The table has been inserted because difficulty has been commonly experienced in adjusting the temperature of the water so as to obtain an exact average of 90° F., and also because it is often convenient to steep the vats last loaded at a somewhat higher temperature than the earlier ones, so as to be able to run all off together (see Report for 1905-6, p. 14).

Temperature (in degrees F.)	90°		93°		96°		99°		102°		105°	
	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.
Period of steeping Java plant	12	30	11	30	10	30	9	30	8	30	7	30
Period of steeping Sumatrana plant ..	10	30	9	45	9	0	8	15	7	30	6	45

It will be seen that this works out a decrease of 20 minutes' steeping for every degree rise in temperature in the case of Java plant, and of 15 minutes for every degree rise in the case of Sumatrana plant. It is, of course, understood that the temperatures referred to are the *averages* during the steeping period (*i.e.*, the *mean* between the temperature in the vat just after filling and that when it is run off), and that the period of time is measured from the time the vat is full until it is

Take temp. at intervals of 3 hours and judge time for running off from average.

opened (see last year's report, p. 9). Many isolated experiments which have not been recorded have been made during the past three seasons at various temperatures within the limits of the above plan, and practically all have been found to conform with the scheme. There is little doubt therefore that, if the provisos which have been mentioned are carefully regarded, it is a safe guide.

Thermometers.

In this connection I may mention that Messrs. Baird and Tatlock of 14, Cross Street, Hatton Garden, London, are prepared to make a special thermometer in accordance with my design for taking the temperature of vats. A specimen instrument supplied by this firm seems to entirely meet the needs of the case and to be thoroughly reliable. Its scale extends from 70° F. to 120° F. and is divided into degrees, so that a single degree is represented by a large divsion of the scale. It is mounted in a copper case provided with a reservoir round the bulb, so that a portion of the water is removed from the vat, which renders an accurate reading easy without the use of an indicator. The price quoted for these instruments is £2 11*s*. per dozen or Rs. 3-3 each. This is exclusive of the cost of freight, which would be very small if a number of thermometers were ordered simultaneously.

Light loading.

In my last report I mentioned that there was reason to anticipate that advantage would be found to attach to loading the vats at a lighter rate than has been customary hitherto, particularly with plant rich in colour-yielding material. Several days "mahai" were devoted to an elucidation of this point. It was found that with Java plant of average quality (40—45% of leaf and ·6—·7% indigotin in the leaf) steeping for 12½ hours at 90° F., the following average efficiencies were obtained with various loads :—

80	maunds per 1,000 cub. feet	92·7% efficiency.
100	,, ,, ,, ,,	88·2 ,, ,,
120	,, ,, ,, ,,	83·8 ,, ,,
140	,, ,, ,, ,,	77·5 ,, ,,

It is thus clearly indicated that lighter loads tend to a higher efficiency; moreover, the losses sustained in the seet-water were not heavier in these cases than is usual. Light loads are, therefore, to be recommended with plant of this quality.

With poorer plant such advantage does not arise. During a few days at the end of "mahai" experiments were carried out with Java plant, in which the leaf and colour contents had already begun to drop, loading at the rate of 80 maunds per 1,000 cub. feet and steeping for periods of 11 and 12 hours. It was found that an average efficiency of only 78·5% was attained at the latter period and of 87% at the former.

A choice seems to lie open, therefore, between decreasing the period of steeping by about an hour for every decrease in load of 40 maunds per 1,000 cub. feet, or maintaining the normal period of steeping (see preceding para.) and loading more nearly up to 120 maunds per 1,000 cub. feet. I am inclined to recommend the latter course, and this recommendation would also apply to Sumatrana plant. These questions are worthy of further investigation.

Alkalis and alkaline mixtures in steeping.

These experiments were carried out in continuation of those mentioned in last year's report, and the matter was gone into very thoroughly since I was desired to confirm, or otherwise, the claims which have been made for the so-called "Glucosode" process.

This substance was prepared and applied in accordance with the directions given in the English patent specification No. 10506 of 1906, and the results obtained by its use were compared, not only with those of the ordinary manufacturing process (*i.e.*, steeping Sumatrana plant 10½ hours at an average temperature of 90° F., and oxidizing with the employment of ammonia gas), but also with the results derived by using in the steeping vat an equivalent amount of caustic alkali to that involved in the "Glucosode" employed, both with and without ammonia in oxidizing. Fourteen hours' steeping was given in these cases, this period having been found the optimum when the particular amount of alkali in question was used. The effect of using ammonia in oxidizing in conjunction with "Glucosode" was also tried. The following results were obtained :—

Process.	Average percentage efficiency.	Average quality.
"Glucosode"	73·2	56%
Ordinary	83·5	63·7%
Alkali equivalent to "Glucosode"	75·7	58·2%
Alkali equivalent to "Glucosode" and ammonia in oxidizing ..	74·3	68·9%
"Glucosode," and ammonia in oxidizing	84·3	55·2%

The "Glucosode" process has thus not given as efficient results as the ordinary one, and, as was to have been anticipated, they are practically the same whether "Glucosode" or its equivalent in alkali is used, that is to say, the other constituents of "Glucosode" are without

effect on the result. By using ammonia in conjunction with "Glucosode" a higher efficiency is obtained, but since no appreciable improvement is shown over the ordinary process, this is insignificant. The reason for the comparatively low efficiency when alkali and ammonia are used jointly is not clear. More experiments are needed on this point.

The quality of the indigo obtained by the "Glucosode" process, and also by that in which an equivalent of alkali was used in steeping, is low, and it would seem that such processes are distinctly to be deprecated on this score.

The practical outcome of these tests is then that, provided due regard is paid to the conditions of time and temperature which have been laid down and an alkali is used in oxidizing, no improvement in yield is to be obtained by the use of alkali, or of alkaline mixtures of the nature employed, in the steeping vat, and the quality of the indigo obtained is apt to be distinctly inferior.

Late "mahai" with Java plant.

"Mahai" was carried out with Java plant during four days in December (3rd to 6th) in order to determine what degree of success might be anticipated at this late season if proper attention were paid to the heating of the water. The temperature of the tank from which our supply is derived averaged about 78° F. at this season, and it was found necessary to heat it to about 96° F. in order to attain an average steeping temperature of 90° F. Under these circumstances the process was as efficient as at any other time during the year, and an average outturn (as determined by analysis) of 18 seers 4 chittacks of 60% indigo per 100 maunds of plant was obtained. The quality was, however, poor, averaging only 44·5%; this might probably be improved by using extra acid in the "mal" boiler. In any case, "mahai" seems well worth doing at this season if the area of plant in a fit condition to cut is sufficiently large, particularly since the cutting is likely to be of great benefit to the plant (see later under "cutting back"). It is to be noted that the quality of the indigo obtained at this season is markedly superior to that obtained from March cuttings (see last year's report, p. 31).

Filtering seet-water.

The apparatus for filtering seet-water recommended by Rawson, and mentioned in my last report, was procured from England early in the year, and given a very thorough trial during the manufacturing season. The apparatus is in type very like a filter-press, but differs from it in that the liquid to be filtered flows through under natural pressure instead of being forced by a pump. The liquid passes through a series of chambers whose walls consist of coarse cloth spread over frames, and the solid matter in suspension is deposited on the cloth whilst

the clarified liquid passes away. The results obtained were rather disappointing for, although a great deal of indigo was retained, it was found that with new cloths filtration was by no means perfect and that, after the cloths became coated with a layer of sludge, filtration was improved, but the rate of flow became so slow that the use of the apparatus on a large scale would be impracticable. Thus an average of only 40% of the total indigo-content was removed from the seet-water during the days the apparatus was under trial, and the average rate of flow works out to nearly 9 hours per 1,000 cub. feet. It is true the seet-water experimented with contained, in many cases, an exceptionally large amount of indigo in suspension, but even when the content was about normal (5—10 per cent. of the total outturn of indigo) the flow was too slow, and the apparatus cannot be recommended for general adoption as it stands. It is, however, a marked improvement over the filter-press tried bv Rawson for the purpose (Report, 2nd edition, p. 86), and it seems subject to several structural modifications which would render its working more rapid and efficient. Some further experiments in this direction should be well worth making.

"Mal" boiling.

Some doubt seems to exist amongst planters as to the exact method which should be pursued in boiling the "mal" if acid is used in the process, for, though Mr. Rawson gives detailed directions as to quantities in his report (new edition, pp. 87 and 95),* the method of application to which he refers appears to have been described elsewhere and to be no longer on record.

The method which has been found to give the most satisfactory results here is as follows :—

The "mal" is heated to about 150° F. immediately after lifting and allowed to settle. The water is then cut off and as large a volume of fresh water added as is conveniently possible. Steam is now turned on and the necessary quantity of acid added. The acid should be previously diluted with about ten times its volume of water, and this is best done in a tub with a hole in the base fitted with a long-handled plug. The tub is supported on poles placed across the top of the boiler, the necessary quantity of water is first poured in, and the acid added; the plug is then removed and the diluted acid allowed to flow into the boiler. After the addition of the acid, the temperature

* It should be remembered that the quantities given refer to commercial acid of about 75 per cent. strength such as is supplied by Messrs. Waldie and Co., and that with the stronger acid (of about 95 per cent. strength) now being introduced into the district, proportionately smaller amounts may be used.

3 – 6 lbs acid per 1000 cb ft val

of the contents of the boiler is again raised to 150° F., the "mal" is again allowed to settle and the supernatant liquid cut off. A large volume of fresh water is now added, and the temperature raised to boiling point, after which the "mal" is run on to the table.

This method will be found to give very much better results than can be attained by adding the acid direct to the "mal," boiling, cutting off and boiling a second time with fresh water, as is customary in many factories. A comparison of the two methods gave the following results :—

	Percentage of indigotin in finished indigo.
"Mal" boiled direct with acid	67·1
"Mal" boiled as recommended here ..	73·0

The improvement would be proportionately greater with indigo of poorer quality.

Indigo powder.

The powder-making machine has also been something of a disappointment this season. The machine made by Messrs. Jessop & Co., referred to in my last report, was found to work very well as regards driving and drying the "mal," but great difficulty was experienced in removing the dried "mal" from the drum. The scraper provided for the purpose did not fit nearly closely enough to remove the whole of the powder, and, after many trials, it has been found impossible to obtain a blade which will do so unless the "mal" is very thick, in which case a coarse and undesirable powder is obtained. A revolving brush has now been substituted for the scraper and promises to be more successful, but this involves enclosing a large part of the machine so as to avoid indigo being blown away and lost. This will be done, and further experiments carried out later on. The difficulties are purely mechanical ones and are bound to be overcome in time.

I think this should be made one of the chief objects of future indigo experiments, for further experience of the European dyer's needs has led me to confirm the view expressed in my first report (p. 16) that it is absolutely necessary that natural indigo be supplied in as convenient and reliable a form as the synthetic substance if it is to compete with it on its own ground. A guaranteed composition is even more important than a form convenient of application, but it is difficult to see how this is to be attained unless powder is made and graded, or

converted into pastes in the country of consumption, in the manner suggested in my first report (*loc. cit.*).

AGRICULTURE.

Manurial Experiments.

The general plan and object of these experiments were described in my first report. I was unable to record much definite result last year owing to the irregularity of growth of the plants on the various plots early in the year, and to destruction of the crop by floods later; I did not, therefore, go into details of the plan of experiment. This year we have more definite results, since it has been possible to obtain two good cuttings from each plot at the normal cutting season. The plant obtained at the first cutting from each plot was weighed, its leaf-content determined, and samples of leaf analysed; the second cuttings were too irregular (mainly owing to drought) to allow of definite results being obtained from weighment and leaf determinations, but samples of leaf were drawn from the total produce of each plot and analysed.

Some conclusions can be drawn from the figures obtained, but they are of an unexpected and largely of a negative character. I include an account of the experiments, however, so that the results may be recorded for what they are worth, and advance the conclusions drawn tentatively, and with the conviction that a good deal more work is required on the same lines before they can be accepted as confirmed.

It will be remembered that the object of the experiments was to determine what specific chemical substance, if any, in the manure applied led to the production of indican (the indigo-yielding glucoside). To this end the plots were divided into two main series, one of which was "seeted" and the other not, and a manure comprising all the substances which could conceivably play a part in the production of indican was applied to two plots in each series. Each of these substances was omitted in turn in two other plots in each series and, finally, no dressing at all was given to two plots in the "unseeted" series and of "seet" only in the "seeted" series. The general arrangement of the plots and the actual dressings given are shown on the next page.

No "seet"	Nothing.	No Potash.	No Nitrogen.	No Phosphate.	Complete.	No Sulphate.	No Magnesium.	No Iron.	1 Kilo Chalk only.	Nothing.	No Potash.	No Nitrogen.	No Phosphate.	Complete.	No Sulphate.	No. Magnesium.	No Iron.	1 Kilo, Calcium Sulphate only.
"Seet" ..	"Seet" only.	No Iron.	No Magnesium.	No Sulphate.	1 Kilo Chalk only.	No Phosphate.	No Nitrogen.	No Potash.	Complete.	"Seet" only.	No Iron.	No Magnesium.	No Sulphate.	500 Grams Calcium Sulphate only.	No Phosphate.	No Nitrogen.	No Potash.	Complete.

Complete =	Potassium nitrate,	Sodium phosphate,	Calcium sulphate,	Magnesium sulphate,	Ferrous oxalate,	(Ferric carbonate on "seeted" plots).
No Potash =	Sodium nitrate,	do.	do.	do.	do.	do.
No Nitrogen =	Potassium sulphate,	do.	Calcium carbonate,	do.	do.	do.
No Phosphate =	Potassium nitrate,	....	Calcium sulphate,	do.	do.	do.
No Sulphate =	do.	Sodium phosphate,	Calcium carbonate,	Magnesium chloride,	do.	do.
No Magnesium =	do.	do.	Calcium sulphate,	Sodium sulphate,	do.	do.
No Iron =	do.	do.	do.	Magnesium sulphate.	....	....

The size of the plots was 1 square yard and the quantities of manurial substances applied were:—

Potassium (and sodium) nitrate ..	60	grams.	
Sodium phosphate (and sulphate) ..	60	,,	
Calcium sulphate (and carbonate) ..	250	,,	(125 grams on "seeted" plots).
Magnesium sulphate (and chloride) ..	60	,,	
Ferrous oxalate (and ferric carbonate) ..	30	,,	

It will be seen that an effort has been made to trace the effect of bases and acids independently of one another. For example, potassium nitrate, which is added to the complete manure in order to provide potash and nitrogen, is replaced by sodium nitrate on the plots on which the effect of potash is traced by its elimination instead of merely excluding the potassium nitrate, since, if this were done, it would be impossible to judge whether any effect produced were due to the lack of potash or of nitrogen. An effort has been made to adhere to this principle throughout, though it was not found possible to do so entirely consistently in all cases. This accounts for the somewhat unusual compounds which have been employed; it must be remembered, however, that these manures were not intended to represent in any sense what might be recommended for application in the field, but were designed to elucidate what is at present a purely scientific problem.

Although the plots were artificially constructed in order to eliminate naturally occurring differences of soil, the duplicate plots were arranged in positions as remote from one another as possible to guard against other influences which might introduce inequality in conditions. This precaution was justified by the results, since the duplicate plots at opposite ends of the series did not give as close figures as were to have been anticipated if constitution of soil were the only factor in the case. But approximately the same *relation* was found to exist between the plots in each set, so that it is justifiable to take a mean between the duplicates in expressing the results. The figures obtained at the first cutting are shown in the following table; they express the mean yield of indigotin obtained from the duplicate experiments in chittacks.

Manurial treatment.	"Seeted."	"Unseeted."
Complete	·278	·188
No Potash	·256	·238
No Nitrogen	·243	·256
No Phosphate ..	·245	·244
No Sulphate.. ..	·245	·246
No Magnesium ..	·286	·228
No Iron	·285	·206
Chalk only	·153	·301
Calcium sulphate only ..	·278	·213
Nothing	·278	·198

It is obvious that in order to be able to draw any positive conclusions from manurial experiments conducted on the plan pursued the complete manure should give the best results of the series, otherwise any ill-effect caused by the various omissions cannot be traced. It will be seen from the above figures that almost precisely the contrary was found. In the "seeted" series the plots receiving a complete manure gave an identical average return of indigotin to those receiving "seet" only, and in the "unseeted" series the complete manure actually gave the lowest figure of all, the blank plots coming next. The indication is, therefore, that indican production was independent of, or actually decreased by, manurial treatment, and there does not seem to be much to be gained at this stage by seeking an explanation of why some of the plots have given higher yields than the blanks in their series. In this respect the indications of the two series are contradiotory; for instance, whereas the "seeted" series shows that an application of chalk only is worse than nothing and that the absence of nitrogen in the manure is the most serious omission, the "unseeted" series shows chalk alone to give the best results and the plot on which nitrogen is omitted the next best. The meaning of this merits further investigation.

The analysis of the plant cut from the plots in September confirms the view that indican production is not stimulated by manurial treatment. As explained above the plant was not weighed or its leaf-content determined on this occasion, but if we assume uniformity in these respects we have, as a result of the analyses, the following relations :—

	"Seeted."	"Unseeted."
Complete	·735	·907
Nothing	·780	·836

A decrease in indican for manurial treatment on the "seeted" plots and only a small increase (which might easily have been nullified if the yield of plant and its leaf-content had been considered) in the "unseeted" ones.

If the indication of these experiments is upheld, it means that indican production must be looked upon as something of the nature of a starvation phenomenon, in which case plant-food is not likely to stimulate its production. I do not mean that it will not stimulate

the *growth* of the plant, for this it undoubtedly can and does do. This was indicated by the cuttings obtained from the "seeted" plots with complete manure, which were amongst the heaviest of the series, but the colour-yield was more than proportionately poor, so that the nett result was as has been described. The theory that indican production accompanies more or less starvation conditions (and it cannot be considered more than a theory at present) seems to carry support from the facts that plant grown under minimum moisture conditions (*e.g.*, plant cut before the break of the rains) has invariably a high colour-content, and that in years of adverse climatic conditions of all descriptions (*e.g.*, the past year) the average colour-yielding power of the plant is frequently abnormally high. This may, of course, be explained to some extent by the stunted growth of the plant and its consequent high leaf-content, but it may well be that this is not the *whole* of the explanation.

Effect of "Seet."

It remains to consider the effect of "seet" in the above experiments. The average yield from the "seeted" plots cut in July was ·255 chittacks, and from the "unseeted" ones ·232 chittacks, so that, although the average analyses were nearly identical, some advantage attached to the former. On the other hand the average of the analyses of the leaf obtained from the "seeted" plots in September showed a content of ·469 per cent. of indigotin, and from the "unseeted" ones of ·927 per cent., which, if an equal yield and leaf percentage is assumed, argues in the other direction. This is only in accordance, however, with the observation commented on in my last report, that plant on "seeted" land ripens, and consequently drops its colour-content, more rapidly than on land which has not been so treated.

Conclusion.

The conclusion to be drawn from these experiments is then that indican production is not stimulated by manurial treatment. On the other hand there must be a limit below which the fertility of the land must not drop, and it is essential to maintain a good physical condition, otherwise the development of the plant is arrested and although its colour-content may be very high, the return per acre is affected. The necessary mean seems to be obtained by the application of "seet" at least a year before the indigo crop is sown.

Plant-Stimulants.

In this connection the experiments with plant-stimulants mentioned in my last report acquire fresh interest, for if the theory that indican production is of the nature of a starvation phenomenon is true, it lends probability to the idea that its production can be stimulated by the slightly adverse conditions which such applications would bring about. I have unfortunately not been able to resume this line of work, but hope to do so at some future time.

Selection. No progress has been made in the selection of the Sumatrana plant this year. Seed of each of the sub-varieties mentioned in my last report was sown in March, but germination was bad, and, in spite of repeated sowings both with and without irrigation, only isolated plants of a few of the varieties were secured. Owing to the lateness of the season and the small stock of seed of some of the varieties remaining, it seemed wiser not to risk further waste, and the seed has therefore been kept for sowing next March.

A start has, however, been made in the selection of the Java plant. Mr. J. G. Turnbull joined the staff of the station as botanist in April, and was engaged on this work until he was obliged to leave us in December. The main objects held in view were :—

(i) Selection for indigotin-content of the leaf.

(ii) Selection for leaf-content.

(iii) The isolation of races by means of botanical characteristics.

The first of these objects necessitated a considerable number of chemical analyses, and a good deal of time was devoted by Mr. Turnbull to acquiring the method of analysis and testing methods of drawing samples of leaf from the living plant. The indigotin-yielding capacity of the leaf of a large number of plants has been recorded, and the best of these will be kept for seed, and the seed sown in due course. It remains to be seen if the plants obtained from this seed maintain the high indigo-yielding capacity of the parent plants, or what proportion thereof do so. Any such plants found must again be kept for seed, and so on, until by gradually eliminating the plants of low colour-content and deriving seed only from such plants as have a high dye-yielding power, a stock of seed which can be relied upon to produce plant of the nature sought is built up.

The large differences which occurs in the dye-yielding power of plants of apparently the same type growing under identical conditions is well illustrated by the following figures selected from analyses carried out by Mr. Briggs in September :—

Number.	Percentage of Indigotin in Leaf.		
	Java.	Natal.	Selected Java.
22	·626	·727	·862 like 16
12	·637	·825	·870
17	·720	·842	·950 like 1
6	·765	·855	·877
18	·787	·875	·887
9	·802	·892	·87 like 33
19	·870	·960	·865 like 36
1	*·885	·964	
16	*·892	*·975	
33	*·900	*1·01	
27	*·925	*1·02	
36	*·952	*1·05	

The first two columns illustrate typical analyses of leaf from plant derived from Java acclimatized seed, and seed obtained from Natal respectively, and show what large variations occur in both cases. Those marked with an asterisk have been selected for seed-bearers. It will be noticed that the average of the figures given for the Natal plant is higher than that of those representing the Java variety, but this cannot be taken as an indication that the former is inherently superior since the Natal plant was stunted and ill-grown, which invariably implies an abnormally high colour-content.

The last column in the above table illustrates the indications which have been obtained of a relation existing between botanical character and colour-yielding capacity. The analyses given are those of the leaf of plants which were selected for analysis by reason of some similarity in botanical detail to one or other of the previously selected plants, and it will be seen that in the cases given the similarity appears

to have held good, to some extent at any rate, with regard to colour yield.

Mr. Turnbull believed he had distinguished six races amongst the Java plant differing in botanical characters as well as in indigotin yielding power. It will be important to verify this observation since, if the characters observed are truly racial, it may considerably simplify the selection problem.

In any case definite results cannot reasonably be expected from work of this kind until some years have elapsed, but there is no doubt that the possibilities involved are enormous and that it is in this direction that further marked improvement in the economy of natural indigo production is to be sought. The enormously increased content of sugar in the sugar-beet, which has been brought about by selection n latter years, is evidence of what can be done in this way. The indigo problem is in many respects a similar one, and there seems every reason to expect that, with a similarly systematic and patient application of selection, equally satisfactory results would be attained.

Production of Sumatrana seed in Bihar.

The possibility of growing satisfactory Sumatrana seed in Bihar has again been demonstrated this year. Several planters kindly sowed Bihar grown seed which I sent them, and reported their results. In every case satisfactory germination was obtained, but in all except one (that of Mr. E. H. Hudson of Rajpore) the crop subsequently died out from drought. The area sown at Sirsiah shared the same fate. Mr. Hudson's figures show that the crop obtained was in every respect equal to that derived from North-West seed. An average cutting over the ten acres sown of just under 100 maunds per acre was obtained, and the plant yielding an average of 8 seers of indigo per 100 maunds. There can now be no resonable doubt that Sumatrana seed can be grown in Bihar if necessary, but the suggestion made in my last year's report that some seed-farms for the purpose should be established in the district has not been adopted, mainly because it was recognised that the cost of production would be greater here than in the North-West. This is no doubt the case, and, since we have at present a satisfactory supply forthcoming from Dasna, it is perhaps unnecessary to consider the matter further until, at any rate, we have progressed a little further in the selection work.

Rate of sowing Sumatrana seed.

On this subject also several planters kindly carried out experiments for me, but, most of them as well as those at Sirsiah, were spoilt by the severe drought shortly after the sowing season. I have again to thank Mr. E. H. Hudson for the following figures showing results obtained by him by sowing at different rates :—

Area sown.	Quantity of seed per acre.	Yield of plant.	Yield per acre.
4½ Acres.	6½ seers	197 maunds.	46·35 maunds.
5 ,,	6 ,,	217½ ,,	43·5 ,,
5 ,,	9 ,,	249 ,,	49·95 ,,
5 ,,	12 ,,	227¼ ,,	45·45 ,,

The seed sown was grown at Dasna. Germination was excellent, but the whole crop suffered severely from drought, so that the yields are all very much lower than they would be under normal conditions. The figures indicate, however, that light sowing is of advantage though, in a year of drought, it is probably unwise to sow less than 8-9 seers per acre.

Java plant.

About a third of the indigo cultivation in Bihar is now under the Java plant, and a very much larger proportion will be under it next season. The average of the estimated returns from Java plant sent in by 31 factories this year is 20 seers 9 chittacks per acre and 15 seers per 100 maunds of plant, against 8 seers 12 chittacks per acre and 11 seers per 100 maunds from Sumatrana. The superiority of the Java plant shown by these figures is thus enormous, particularly when the yield per acre is considered. The conditions of the past year have, no doubt, tended to make the contrast abnormally marked, since the drought which succeeded the Sumatrana sowings did the crop immense harm, whilst the Java plant was affected comparatively little owing to its having it root-system already well established. But even if allowance be made for this, there is still sufficient margin in favour of the Java plant to amply justify its wide introduction.

Our results at Sirsiah show an even greater contrast if yield per acre is considered, but this is due to our obtaining only one good cutting from the Sumatrana plant (owing to the lateness of the season before the crop was properly established) and two, and in some places three, from the Java. The figures obtained from analysis and calculation as 60% indigo show an average of 19 seers 7 chittacks per acre and 18 seers 6 chittacks per 100 maunds of plant for Java; and 10 seers, 7 chittacks per acre and 14 seers per 100 maunds for Sumatrana. Actual weighment gives an average of 19 seers 3 chittacks per acre and 16 seers 1 chittack per 100 maunds for Java; and 8 seers 1 chittack per acre and 10 seers 9 chittacks per 100 maunds for Sumatrana.

Quality.

Our average quality for indigo made from Java plant is 61·1% and from Sumatrana 59·5, but the latter involves several dates on which "Glucosode" and other alkaline substances were used in steeping, so that the comparison is a little unduly in favour of the Java produce. There is thus very little to choose in point of quality; both are notably inferior to the indigo made last year. The comparative inferiority of this year's produce seems to be characteristic of the whole of the Bihar outturn.

Sulphuric acid treatment of Java seed.

This method of treating seed in order to promote germination, which was described in my last report, has been generally adopted and has given very satisfactory results. Two points have arisen in connection with it during the year. The first led to the issue of a circular by Mr. Briggs in September last. It was found that if sulphuric acid of the strength recently introduced into the district were used for the treatment, a great deal of seed was destroyed, even though it were well ripened. This is due to the fact that this acid is more concentrated than that which has been supplied hitherto, and has consequently a more violent action on the seed-coat. The difficulty can be easily surmounted by leaving the seed in contact with the acid for only 20 minutes, instead of for the half hour originally recommended in employing weaker acid. The 20 minutes are counted from the time the acid is first added and includes the five minutes devoted to mixing it thoroughly with the seed. Particular care must be taken in applying the first washing water when concentrated acid is used. This must be added in as large a volume as possible and the seed *immediately* stirred.

The second point which requires modification of the original directions is with regard to the *quantity* of acid to be used. It has been found that three seers of acid is sufficient to thoroughly wet a maund of seed if the stirring is conducted with sufficient care. This entails a large saving of acid and is, therefore, to be recommended.

Sowing Java seed.

The question of the best time of year to sow Java indigo still seems to be a vexed one amongst planters, and some discussion has taken place on the subject during the past year. There seems to be little to be gained by such discussion, because it is obviously impossible to lay down a hard and fast rule on the subject which shall be applicable to all conditions. So far as it is possible to generalise, all evidence goes to show that October is the best month under average normal circumstances of soil and climate, but decision must depend on the climatic conditions of each year and local knowledge of the soils dealt with. In high lands, and in exceptionally dry years, the seed may no doubt

sown earlier with advantage, and many advantages seem to attach sowing in the rice crop, but it remains to be seen how far this ɩn is generally applicable.

Cutting back.

With early-sown crops cutting back seems to become necessary fore February, and I am inclined to think that it should be done as ɔn as the plant begins to flower. This seems a better course than that leaving the plant until February and then cutting. It not only ests premature seeding, but also makes the chance of manufactur- from the cuttings a better one, since the indigotin-content of the nt gradually declines as the cold weather advances and is at a nimum after the seed has ripened. If the cultivation is sufficiently ge and the plant tall enough, there seems no reason why the cut- gs should not be used for manufacture in November or December, vided due precautions are taken in heating the water (see p. 8). would certainly be unwise to leave such plant untouched until ordinary cutting season since not only is the strain of useless seed- duction put upon the plant, but also a tall "sticky" habit is uced.

The experience gained of cutting back October sown plant in Feb- ry is again of a most varied character, but it seems generally to firm the opinions expressed in my last year's report. I do not nk there is much to add to those opinions. My view on the subject cutting back in general is that the aims should be to prevent prema- e seeding, and the development of a woody stem, and to promote nching in thin crops.

Cutting for "Mahai."

insert a note on this subject, since there seems to be a growing dency amongst planters to cut the Java plant at too great a height n the ground. Coolies are apt to do this in order to avoid the effort ded to cut through the woody base of the stems; but it should be y carefully avoided. Each successive cutting must necessarily somewhat higher than the last, and if, therefore, every effort ot made to keep as low as possible, a great length of woody stem have been developed before the last cutting is reached. This is only an undesirable habit of growth opposed to healthy branching, it also involves risk of causing the stem to split in cutting and expose a length of interior tissue, which provides a lodging place any spores of parasitic fungi which may be about. There seems e evidence that this latter cause frequently leads to the production disease and consequent loss of "khoonties." The plant should, refore, be always cut as nearly within two inches of the ground as sible at the first cutting, and proportionately low at subsequent ings.

Java seed production.

The farms established in 1906 for the production of Java seed, in Bihar, distributed their first crop in April last. The outturn was not so large as had been hoped, averaging only nine maunds per acre over the three farms, but the quality was generally good though a small proportion turned out badly. This was apparently due to its having been picked in an unripe condition. It is, of course, very difficult to ensure sufficiently careful plucking over a large cultivation; but every effort should be made to do this since there can be no reasonable doubt that sowing unripe seed leads to the production of weakly plants very liable to die out under any adverse condition, or, if surviving, of very poor growth. There is evidence, too, to indicate that plant derived from unripe seed is liable to have a poor dye-yielding capacity. Some seed received from Buluwayo in November 1906 was tested for germination capacity, and 20 per cent. of the seeds were found to germinate without treatment. Some of this seed was, therefore, sown without treatment and some after treatment with acid (which, of course, eliminates the unripe seeds). The leaf of the plants obtained from each was analysed in August last with the following results :—

	Percentage of indigotin in leaf.
Plant from ripe seed ..	·615
Plant from unripe seed ..	·495

A difference of about 20 per cent ! If this is confirmed, it is a very important consideration, though, luckily, acid treatment of the seed destroys most of the unripe ones.

A series of experiments on methods of seed cultivation was started in October, 1906, and the results were obtained last spring. The points investigated were :—

(i) The effect of spacing the plants at various distances.

(ii) The effect of "topping" the plants (*i.e.*, nipping off the leading shoots to induce branching) in June.

The experiments were carried out on plots 40′ × 50′ selected in a very even field, and each one was performed in duplicate. The duplicate plots agreed fairly well, and the following table gives the averages of the results obtained :—

Experiment.	Yield.		
	M.	S.	Ch.
Unthinned and uncut	1	4	12
Do. and "topped"	1	22	9
Plants 2′ apart		39	8
,, 4′ ,, ...		20	13
,, 6′ ,, ...		17	9

Thus, from the point of view of yield, distinct disadvantage attaches to spacing the plants but advantage to "topping." The principle of "topping" has accordingly been adopted on the seed-farms this year.

It remains to be seen what effect, if any, the various methods of cultivation have on the quality of the seed. There is not much to choose in this respect between the seed derived from the various plots by inspection or tests of germination capacity; all are good. Samples from each plot have been kept, and the plant obtained from each will be carefully grown and examined. It seems likely that spacing will improve the quality of the seed, since, in so doing, an effort is made to select specially vigorous plants; but none was done on the seed-farms this year, partly because the drought early in the year had very largely thinned out the weakly plants naturally, and partly because a large yield seemed the consideration of greatest importance at the moment.

This year's harvest from the seed-farms is now being gathered. It should be of first-rate quality, since it was grown, from the best stock which could be obtained, with every care; but, unfortunately, the total outturn is likely to again be low, since one of the farms has suffered badly from an attack of fungoid disease.

Further experiments in seed cultivation were started here last year, and the crop will soon be ready to gather. The new points which are being tested in this series are :—

(i) The effect of spacing and "topping" jointly.

(ii) The effect of growing the plant in strips of various widths with fallow strips alternated.

Deterioration. More has been heard of the deterioration of the Java plant this year, but there is no evidence that such deterioration has taken place, or is likely to take place, where proper attention has been paid to the principles of seed-production dealt with in my past reports. The following figures, comparing the returns obtained this year with those of last, seem to argue strongly against any deterioration having taken place so far :—

	Yield of Indigo.			
	Per acre.		Per 100 mds.	
	S.	Ch.	S.	Ch.
Average of 20 concerns in 1906 ..	14	6	14	13
,, 31 ,, in 1907 ..	20	9	15	0
Sirsiah 1906	....		17	0
,, 1907	19	3	16	1

The same indication is afforded by the results obtained from seed imported from Natal sown here this year. Java seed grown at Dasna and in Bihar, respectively, was sown in the same field, and the crops cut and weighed separately. The following average returns of plant per acre were obtained :—

	Yield of Plant per acre.	
	M.	S.
Natal	78	14
Java (from Dasna)	81	4
Java (from Bihar)	105	0

Thus the Bihar-grown Java seed has given very much the best results as far as weight of plant is concerned. It was not possible to manufacture the cuttings separately.

Fungoid diseases and a Pest. During the past year two fungoid diseases and an insect pest have attacked indigo in various parts of the district. Early in July a

disease causing the death of scattered individual Sumatrana plants was reported by Mr. W. E. Cox, of Mullayah, and Dr. Butler, the Imperial Mycologist, was consulted as to its nature. Dr. Bulter found that death was caused by a fungoid disease closely allied to the "wilt disease" of 'Rahar,' which frequently leads to very considerable losses; he, therefore, considers the attack a somewhat serious matter. He advises that all diseased plants should be removed and destroyed, and that indigo should not be planted in fields in which the disease has appeared for three years. The disease seems to be spread over a very wide area, though not very severe in any one place; and it is doubtful whether the affected lands could all be left out of indigo cultivation for three years without very considerably curtailing the cultivation. Dr. Butler suggests that the Java plant may be found less susceptible to the disease than Sumatrana. Fortunately this appears to be the case, and it is probable that, with the wider establishment of the Java plant, little trouble will be given in future by the disease.

About the same time as the "wilt disease" was reported, several planters observed the growing shoots of both their Sumatrana and Java plants commonly curling up and causing considerable arrest of growth. It was thought possible that this might have some connection with the "wilt," and I accordingly sent specimens of both varieties of plant showing the symptoms to Dr. Butler for examination. After carefully going into the matter Dr. Butler reported that no trace of the "wilt disease," or of any other parasitic fungus, could be found in the plants; and the question accordingly dropped for the time being. Later in the year the attention of Mr. Lefroy, the Imperial Entomologist, was drawn to the matter by Mr. Briggs. Mr. Lefroy found that the curling of the shoots was occasioned by the attack of an insect known scientifically as *Psylla Obsoleta*. Mr. Lefroy's report on the subject has been circulated amongst members of the Association, and I need, therefore, refer to it no further.

Finally, another fungoid disease has recently appeared amongst the seed-farm plant at Dowlutpore, and has necessitated the destruction of a great deal of the crop. Dr. Butler has the matter under observation, but has not yet been able to report on it. Fortunately, this disease seems to have been confined to Dowlutpore. With regard to the question of the possibility of spreading it by means of the seed derived from apparently healthy plant on the farm, Dr. Butler cannot yet express a definite opinion, but advises that such seed should be treated with an antiseptic before distribution, by way of precaution. This advice will be very carefully followed.

The occurrence of all these diseases within one year has occasioned some disquietude, and there is no doubt that they will have to be very carefully watched in the future. But it must be remembered that the year has been one of very exceptional climatic conditions, which have tended to produce weakly plant easily succumbing to any attack, and that with a restoration of more normal seasons, and a wider adoption of Java plant, there is every reason to hope that no increase of disease will take place. On the other hand a circumstance on which Mr. Lefroy lays stress in his "Psylla" report is a very pertinent one. By the introduction of Java plant a condition of affairs has been set up under which indigo is standing all the year round, and harbouring places for parasitic insects and fungi are afforded in the winter where formerly they did not exist. There is thus bound to be an increased tendency to carry diseases on from season to season. For this reason alone every precaution must be taken in future to promote the healthiest possible growth of plant by using good seed and regarding every other condition of careful agriculture.

Conclusion. Finally, I have again to express my thanks for the valuable assistance which has been rendered by the members of the Sirsiah staff during the year, in particular to Mr. Briggs who carried on the work of the station under very difficult circumstances in my absence on leave, and to the planters who have kindly co-operated with me in some of the experiments.

REPORT

OF THE

INDIGO RESEARCH STATION, SIRSIAH,

(Under subsidy from the Government of Bengal.)

FOR THE YEAR 1908–1909

BY

CYRIL BERGTHEIL.

INTRODUCTION.

Research work on natural indigo is just now at a transition stage, since we have practically disposed of all questions connected with manufacture, and have not yet made a systematic start on the biological side of the work from which much may be hoped in the future. This is due, mainly, to the fact that we have again been without the services of a botanist to conduct this work, so that it has only been possible to keep things going, pending an appointment being made. Also, in the state of uncertainty as to the continuation of the work at Sirsiah, or elsewhere, it did not seem advisable to embark upon experiments which might never be brought to a conclusion.

The following report contains an account of such work as has been done in the biological direction and on the general outstanding questions connected with agriculture and manufacture.

DYE TESTS.

During the past year we have carried out a number of comparative dye tests of synthetic indigotin and natural indigo in the dye-house referred to in my last report. Our object has been to determine the relative dyeing-power of equal quantities of indigotin in the natural and synthetic forms under equal conditions, but, although we have gone into the matter as fully as the facilities at our disposal would admit, the results cannot be considered by any means conclusive in one direction or the other.

We have used the ordinary B.A.S.F. 20 per cent. paste, and natural indigo in the form of sterilised "mal," and have worked exclusively on the dyeing of wool in the hydrosulphite vat. Our vats hold about 130 gallons of liquor, and we have taken three dips of half an hour, three quarters of an hour, and an hour, respectively, using 2,000 grams of yarn for each dip in every case.

We have, however, found it most difficult to make up our vats so as to attain absolute equality of conditions. The quantity of indigotin in solution and the degree of alkalinity of the vats, can be fairly easily regulated and checked, and, if necessary, equalised, before dyeing is commenced; but this is not the case with regard to the hydrosulphite. We have invariably found that, if an equal quantity of hydrosulphite, sufficient to completely reduce the indigotin in both cases, is added to each vat, the natural dye gives the better results; but this does not seem to be in any way due to a superior

dyeing-power on its part, but to the fact that a given quantity of it is capable of oxidising, and so rendering inert, more hydrosulphite than the quantity of the synthetic substance containing the same amount of indigotin. This is, no doubt, due to the action of the bodies, other than indigotin, contained in natural indigo. The result is that, if equal quantities of hydrosulphite are added to both vats to begin with, a larger excess of it is left unoxidised in the synthetic vat. This invariably leads to poorer dyeings in a given time. It is therefore necessary to adjust the quantity of hydrosulphite in both vats, so that exactly the same excess is present in each case. We have been unable to do this chemically, and have therefore had to rely on the appearance of the vats, and the results of the dyeings, to determine the point.

It is impossible, therefore, to say that under equal conditions equal results were obtained; all one can say is that we have been able to arrive at conditions in which, with the same amount of indigotin in solution and the same degree of alkalinity, the same results were obtained for the first three dips.

But the chief difficulty has been in checking the dyeing processes by analysis. In order to make absolutely certain that two vats are dyeing under conditions of identically equal value, it is necessary to show, not only that the same shade is obtained by dipping the same amount of yarn for the same period in each case, but also that, in order to attain that shade, precisely the same amount of indigotin is removed from each vat; otherwise the shade might be obtained by a less expenditure of indigotin in one case than the other. This necessitates analysis of the vat liquor after each dip. Now in removing the yarn from the vat, a large amount of the liquor adheres to it and is oxidised and deposited on the surface of the fibre as indigotin. With the utmost care in squeezing out the material through rollers this cannot altogether be avoided, and it is clear that the dye which is thus deposited means a loss to the vat which is not represented by the actual dyeing result obtained. This deposit is, of course, removed by the washing operations subsequent to dyeing, before the shades are compared, but it is thereby lost beyond recovery for analytical purposes. In working with small vats the amount of indigotin thus removed is a large proportion of the amount fixed on the fibre, so that the error introduced into the determination of how much indigotin has been extracted from the vat, in order to produce a given shade, is correspondingly large. Moreover a very small error in the measurement of the depth of the liquor in the vat introduces a comparatively large error into the determination. We have in fact found that the attempt to check the changes in the concentration of the vat

liquor in indigotin after each dip was quite useless, the results obtained being frequently quite out of keeping with the differences in shade obtained on the material. It has, for instance, occurred that analysis of the vat liquor showed that more indigotin had been taken out of the vat by the second dip than the first, whilst, on the other hand, the first dip showed a darker shade than the second.

The question which is the better dye cannot, therefore, be finally answered by our experiments. Judging by a mere comparison of the shades obtained from our dyeings conducted under certain conditions, the results are the same, so long, at any rate, as the vats are fairly concentrated; but it is still an open question whether one does not "go further" (from the dyer's point of view) than the other. In our experiments only about 10 per cent. of the total indigotin present was removed from the vats in each case, and it is quite possible that any residual advantage which might exist in either case, did not come perceptibly into play.* Moreover, we have frequently observed that the synthetic dye shows more tendency to wash off the wool after dyeing than the natural, that is to say the latter seems to be fixed more firmly on the fibre. In comparatively small tests, like ours, the influence of a factor of this sort, though seen, does not have any perceptible effect on the results, but on a large scale it may make all the difference in the value of the dyes, and it is possible that this alone explains the superiority of natural indigo which many dyers have observed. It does not, in fact, seem improbable that this is so, since it may well be that the bodies other than indigotin in solution in the natural vat lead to the deposition of the indigotin in a physical form which is more easily held by the fibre, and that glue, which the synthetic makers recommend for use with their preparation (and which we used throughout our experiments), does not have the same effect.

I do not make these comments from a desire to shirk a complete admission of equality, but because I have so frequently received assurances from practical dyers that the natural dye does, indeed, "go further" in their vats, and it may be that an explanation lies in the

* It may be contended, that this point could have been settled by taking a larger number of dips, and so exhausting, or nearly exhausting, the vats. But this would have been of very little use. Since the vats decrease in concentration after each dip by an amount not truly represented by the indigotin fixed on the material, the error in estimating the consumption of indigotin necessary to produce the shades obtained increases with each dip, so that it might well be that the vat which would have been first exhausted would have arrived at that condition *not* by reason of the amount of material it had dyed, but because of the amount of indigotin which had been mechanically removed and lost from it.

points we have not been able to investigate. The experiences of practical dyers, to which I refer, are not obtained with vats made up in special and peculiar ways; these can, no doubt, be prepared so as to show superior results, for the first few dips at any rate, with either dye. For instance, as I have shown above, a superior result can always be obtained with natural indigo by adding to each vat an equal quantity of hydrosulphite, sufficient to completely reduce the indigotin in both cases, or, as the Cawnpore test showed, by having a larger excess of alkali in the synthetic vat; and, conversely, by adding only just enough hydrosulphite to reduce the indigotin in the synthetic form, superior results could be obtained with it, owing to the incomplete reduction of the indigotin in the natural indgo. But the comparative trials made by practical men are independent of all these, and other, variables. They are generally made with chemical* vats, and extend over many weeks or even months. The results are usually expressed in money values by those who carry them out, since their object is to satisfy themselves on a matter of considerable financial importance to them; they can, however, easily be translated from this into relative values per unit of indigotin. Only recently I have heard of a comparative trial extending over six months and involving the dyeing of some thousands of pounds of materials with each dye, which showed a very considerable superiority for natural indigo when the results were expressed on the unit value of indigotin.

Trials of this kind seem to afford the only way by which the point can be settled. If the scale is large enough the errors, to which I have referred above, assume a sufficiently small relative magnitude to be negligible; and the continuous working of the vats for some months gives full opportunity for utilising any residual advantage which may exist in the case of either dye and eliminates any possible inequalities due to the vats being made up differently.

I think it would be well worth an effort on the part of the natural indigo industry to have such large-scale trials carried out under reliable supervision at some of the larger wool and cotton mills in India.

MANUFACTURE.

Manufacture could not be commenced until rather late in the year (July 21st) owing to the very short rainfall and consequent lack of

* With fermentation vats it is also frequently stated that natural indigo gives superior results, but in this case the explanation may be an entirely different one, since it is very probable that the constituents of natural indigo other than indigotin play an important part in setting up the necessary conditions of fermentation.

water in our tank; the same cause led to very slow growth of the "khoonties." The result was a very short "mahai" season, but sufficiently long for the work which remained to be done. Excepting the filtration of seet-water and the preparation of indigo-powder, the only important point in manufacture remaining for investigation was the question of rate of loading. The whole of "mahai" was ther.fore devoted to this point.

Rate of Loading.

Java plant.

The experiments have fully confirmed the indications, recorded in previous years, of the benefit to be derived from light loading with Java plant of good quality. Vats were loaded each day at the rates of 80, 100, and 120 maunds per 1,000 cub. feet respectively, manufacture was carried out in the way I have recommended (*i.e.*, steeping at an average temperature of 90° F. for 12½ to 13 hours, according to the quality of the plant, and oxidising by Rawson's ammonia-gas process), and the efficiencies were determined in the manner described in previous reports. The plant dealt with can be divided into two classes, the one having an average leaf-content of 40 per cent. and an average indigotin-content of the leaf of ·8 per cent., and the other an average leaf-content of 35 per cent. and an indigotin-content of the leaf of ·7 per cent.; it will be convenient to consider the results under these two headings. The following average percentage efficiencies were obtained with the two classes of plant :—

	Load per 1,000 cub. feet.		
	80 maunds.	100 maunds.	120 maunds.
Superior plant ..	89·2	80·2	75·3
Inferior plant ..	70·8	81·0	67·8

Thus the superior plant has given the most efficient process with the lightest load, whilst the inferior plant gives the best results with the 100 maund load. The advice given in last year's report thus receives confirmation. Good quality Java plant should, accordingly, never be loaded more heavily than 80 maunds per 1,000 cub. feet, and the load should be increased as the quality of the plant falls off. No opportunity occurred for experimenting with plant of *very* poor quality this year, and I cannot, therefore, give definite figures on the rate at which such plant should be loaded; but it is doubtful if 100 maunds per 1,000 cub. feet should ever be much exceeded with Java plant,

and 120 maunds is certainly the maximum limit. The indigotin content of the leaf of this plant rarely falls much below ·6 per cent. in practice, and if the leaf-content is very low, as is sometimes the case in a year like the past when manufacture has to be perforce delayed owing to lack of water, it is advisable to cut only the tops of the plant for manufacture. If this is done, the quality of the plant put into the vats need very seldom fall below that limit at which loading at 100 maunds per 1,000 cub. feet is to be recommended.

Sumatrana plant

The amount of Sumatrana plant available for experiments this year was very small indeed, owing to the drought, but, as is usually the case in these circumstances, it was of a very fine quality. The average leaf-content was 51 per cent.; and the average indigotin-content of the leaf ·6 per cent. Steeping this plant at the rate of 80 maunds per 1,000 cub. feet for 11 hours at an average temperature of 90° F. an average efficiency of 93·6 per cent. was obtained. This is exceptionally high and would probably have been reduced had more experiments been possible. It must not, however, be taken that as light loading as 80 maunds per 1,000 cub. feet is to be generally recommended with Sumatrana plant. In years of ordinary rainfall, when the plant makes rapid growth, 40 per cent. of leaf and ·5 per cent. of indigotin in the leaf is a high estimate of average quality, and in this case loading should not be lighter than 100 maunds per 1,000 cub. feet. On the other hand I do not think 120 maunds per 1,000 cub. feet should be exceeded in any circumstances.

Efficiency.

It will be seen that the average efficiency of the processes worked under the best conditions, described in the preceeding sections, works out to almost exactly 85 per cent., if the high figure for the Sumatrana plant, which is probably due to an insufficiency of experiments, be excluded. This confirms the opinion I have frequently expressed in past reports, that this degree of efficiency in manufacture may be attained if the advice which has been given by Mr. Rawson and myself is followed, and the processes recommended are employed.

Since this is probably the last report in which I shall have occasion to refer to this question of the efficiency of the manufacturing process, and since some controversy has centred round the point of late, I should like to take the opportunity to make the view I have arrived at, as a result of the past seven years' work, perfectly clear. By the statement that an efficiency of 85 per cent. may be attained if Mr. Rawson's advice and my own is followed, I mean that, in these circumstances, 85 per cent. of the total indigotin-yielding substance contained in the plant may be actually converted into indigotin. I do *not* mean that this efficiency is invariably obtained, for under the best

conditions it is subject to at least 5 per cent. variation in either direction, nor that this 85 per cent. of the total indigotin available from the plant is actually obtained in the finished product, for there are the mechanical losses in the processes subsequent to oxidation to consider, and these frequently account for loss of 5 to 10 per cent.; still less do I mean that the process as usually carried out by planters attains this efficiency, since essential points are frequently disregarded, which leads to further loss. My contention is that, if the steeping process is carried out as I have advised, and Rawson's ammonia process is used in oxidising, the average efficiency (as determined by the relation between the amount of indigotin obtained in the oxidising vat and that which it is possible to obtain from the plant put into the steeping vat), taken over a large number of days, is in the close neighbourhood of 85 per cent.

This figure has been arrived at from a consideration of the results obtained from some hundreds of separate vat experiments, but it, of course, ultimately depends upon the methods employed for the analysis of the plant and the produce, and it is in regard to these analytical methods that some recent investgators have criticised my conclusion adversely. It would be out of place in this report to go into the details of their criticism, and I have done so fully elsewhere. All the points on which it is based have been most closely re-examined here in the light of the new work, and it has only served to confirm the original conclusion. We have, in fact, during this last manufacturing season. employed, as far as possible, the new analytical methods to determine the efficiency of the manufacturing process on five days (18 vats) side by side with the older methods. The results obtained have agreed as closely together as any two determinations by either series of methods can be relied upon to agree between themselves, that is to say the limit of difference has been about 6 per cent. It is true that this difference has invariably been in the direction of showing a lower efficiency by the newer methods, but it is a question whether this cannot be partly explained by errors inherent in these methods, and, in any case, it is within the possible limit of accuracy.

In previous reports I have expressed the opinion that, since so high a degree of efficiency can be attained by existing methods of manufacture, it is useless to expect further improvement, and, for this reason, I have advised that experiments on manufacture should be discontinued after this year. I do not consider that the attempt to attain the remaining 15 per cent. would justify further work in this direction mainly for economic reasons. It *could* no doubt be attained. If, for instance, it were feasible to extract the plant with boiling water

and precipitate the indigotin chemically from the extract, a very close approach to quantitative conditions of manufacture could be reached; but, in the first place, this would involve working on the leaf only, and, even if this were economcally possible, which it is not, it would mean entire reconstruction of the existing factories, which would only be justified by a far greater improvement in manufacturing conditions than a margin of 15 per cent. renders possible.

With the existing system of manufacture I am strongly of the opinion that an average efficiency higher than 85 per cent. cannot be attained. It is well known that at least 5 per cent. of the total avail-able colour is left upon the plant in the steeping vat, and all efforts at the recovery of this have failed. There is thus only 10 per cent. left for further experiment. In a recent paper (Journal of the Chemical Society, vol. xci, p. 279), Messrs Perkin and Bloxam have shown that there is a strong probality that some of the brown impurities which occur in natural indigo are derived from indoxyl, and thus represent definite losses to the manufacture of indigotin. This may, and probably does, account for part at any rate of this remaining 10 per cent. of the total indigotin available from the plant; but, even if this can be proved to be the case, I do not think that further effort to avoid the change into brown products taking place, and so afford a gain of, at the maximum, 10 per cent. to the process, is likely to be profitable. All the work of the past ten years has shown that it is not to be done in any simple manner, and the end would not justify the employment of any more revolutionary means.

In my opinion, therefore, we must rely on what a study of our problem from the biological standpoint can accomplish for any further help which science can render to the industry. I shall have occasion to refer to this again later on.

Filtering Seet-water.

The experiments which have been conducted on the filtration of seet-water have not been a success. The filtering apparatus mentioned in last year's report was lengthened, and cloths of a looser texture were tried, but in no case could we obtain satisfactory filtration in a reasonable time. It seems to be absolutely necessary to use cloths of as close a weave as those originally supplied with the apparatus in order to get anything like complete filtration, and, even then, this is only the case after the cloths have become coated with sludge. In these circumstances filtration is far too slow to be practicable. It is essential that filtration shall proceed rapidly, not only in order that it may be possible to deal with the large volume of liquid produced daily in an ordinary factory, but also because if the filtration is slow putrefaction takes place.

Considering the results of these experiments in conjunction with those of Rawson with a filterpress worked by a steam-pump under pressure (Report: 2nd edition, p. 86) it would seem that the precipitate suspended in seet-water is of too slimy a nature for satisfactory filtration under any practical conditions, and that further experiments in this direction are not likely to be profitable.

Sedimentation.

In this case the lesson to be learnt is that every precaution should be taken in the method of oxidation to promote good settling of the "mal" and so avoid losses in the seet-water as much as possble. Rawson has shown that the use of alkalis in oxidising promotes this settling, and his ammonia process affords an extremely convenient method of applying an alkali. The difficulty of securing efficient filtration of seet-water thus provides an additional argument for the general adoption of this method of oxidation which I have so often urged.

Failing ammonia, caustic soda may be used with advantage in oxidising, with a similarly beneficial effect on the settling of the "mal" (Report: 2nd edition, p. 74).

A few experiments were carried out here this season on the effect of alumino-ferric on the settling of the "mal." The seet-water was of exceptionally bad quality, an average sample containing ·006 per cent. of indigotin in suspension (11 per cent. of the total produce). The samples were taken for analysis from the supernatant liquid after oxidation was complete and the vats had settled as much as possible. Alumino-ferric was then added at the rate of 2 seers per 1,000 cub. feet and the blower turned on again for a few minutes, after which the vats were again allowed to settle and samples of the supernatant liquid were again taken for analysis. The results showed that there was now only ·003 per cent. of indigotin in suspension, so that 50 per cent. of the loss had been saved by the treatment.

Alumino-ferric.

Alumino-ferric is thus to be recommended for this purpose. It is easily and cheaply obtained (through Messrs Balmer Lawrie & Co., of Calcutta, at about Rs. 70 per ton, or Rs. 2 for a slab of about 51–52 lbs.), and cannot affect the quality of the indigo in any way provided acid is used in boiling the "mal." The use of acid after alumino-ferric is essential, otherwise it will have an adverse effect on the quality.

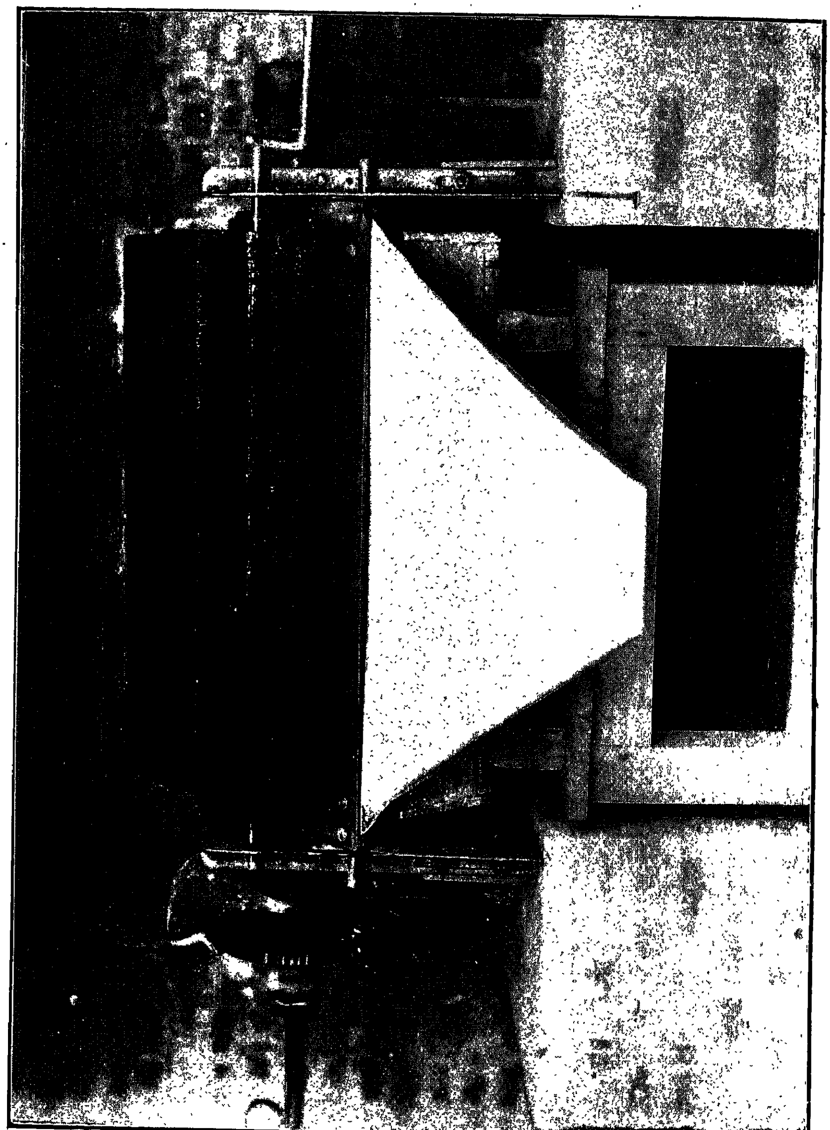
I would advise all planters (more particularly those who do not habitually use an alkali in oxidising) to keep a stock of alumino-ferric in their factories, so that, in the event of bad settling, it is at hand for application. The necessary quantity, allowing 2 seers for every 1,000 cub. feet of liquor to be treated, should be pounded up as finely as possible and dissolved in water. The wheel or blower, should then

be restarted, and the solution be poured into the vat when it is in thorough agitation. The agitation should be continued for 5 minutes or so and then stopped and the "mal" allowed to settle. A quan tity of sulphuric acid equal in weight to twice that of the alumino ferric used should invariably be added to the boiler after this treatment.

This method of sedimentation has been found particularly useful this year when a late "mahai" has been carried out. Bad settling is apt to result from the gummy nature of the stem of the Java plant late in the year, and it is worth mentioning in this connection that the steeping water should not in such case be heated to a higher temperature than is necessary to attain an average of 90°F. over the steeping period.

Water purification. Alumino-ferric is also useful for water-purification, in fact it is made for this purpose. The lime and permanganate treatment recommended by Rawson (Report: 2nd edition, pp. 36 and 91) is usually all that is needed for the water used for steeping, but in certain cases, more particularly when it is stagnant and is rendered impure by vegetable growths, alumino-ferric will be found more effective. It is applied in a similar manner to that recommended for the sedimentation of seet-water, and the same quantity may be used; but, in this case a fresh supply of alumino-ferric is not necessary for every fresh lot of water to be purified, and there is no necessity to use sulphuric acid in the boiler in connection with it. The alumino-ferric may be put into a perforated wooden-box so placed that the water flowing into the reservoir passes over and dissolves it, but it is better to dissolve the necessary amount in a separate vessel and then add the solution to the water in the reservoir, which is kept vigorously stirred meanwhile. The main outlet from the reservoir should be some distance above the bottom so that the sludge may settle and not be drawn off with the water, and there should be a second outlet opening out of the bottom, if possible, so as to allow for the removal of the sludge when necessary. The sludge need not be removed after each purification, and it will be found that after some quantity has accumulated it will serve to purify several lots of water without removal of the alumino-ferric; it is only necessary to stir up the sludge and allow it to settle again each time the reservoir is filled. The sludge need only be removed when either too much has accumulated or it ceases to be effective.

Indigo Powder. The modifications of the powder-making machine mentioned in last year's report have led to more satisfactory results this year than we have previously obtained. A few pounds of powder were made and more could easily have been prepared had the machine been work



ing longer. The dried "mal" comes off the machine in the form of thin flakes which can readily be ground to a fine powder whilst still warm.

The annexed plate shows the machine as it now stands. It is not yet by any means perfect: a wire brush would be much better than a bristle one, and the working of the machine is, at best, a good deal too slow for practical application on a wide scale. We have, however, heard of a machine which can be supplied ready-made by an Edinburgh firm which works on identically the same principle as that which we have employed, and should be at least equally efficient, and very much faster in working. This machine is made for the preparation of dessicated milk and similar commodities. It has two drying cylinders on to which the liquid to be dried is fed from hoppers, and the spreading of the liquid on the cylinders is done mechanically. Judging by this year's experience of our experimental machine I think there is little doubt that this will provide exactly what is required. A machine has been ordered from the makers, and it is hoped that a thoroughly practical trial may be made with it during next manufacturing season at one of the larger factories.

AGRICULTURE.

Manurial Experiments.

The experiments on the application of manures to indigo recorded in my last report indicated that the production of indican could not be stimulated by any ordinary treatment, and, in fact, that the provision of plentiful plant-food tended to react in the opposite direction. As an outcome of these experiments, and of other evidence which seems to point in the same direction, I put forward the theory that the production of indican is a phenomenon which accompanies semi-starvation conditions, that is to say that the smaller is the excess of plant food on which the plant has to draw over the minimum necessary to sustain healthy development the greater proportionately is the production of indican. This theory requires, of course, considerably more experimental support before it can be accepted. It would perhaps be best tested by a series of experiments on similar lines to those described in my last report carried out in pot-culture, so that other conditions (such as those of moisture, etc.), as well as the provision of plant-food, might be under as complete control as possible. I do not think that anything is to be gained by further manurial experiments of the ordinary sort until a very thorough scientific investigation of this kind into the effect of various conditions of environment on the production of indican has been carried out. Such an investigation must involve a great deal of work and must necessarily take a

ong time to bring to a conclusion, and I have not started it this year because it did not seem advisable to do so in the state of uncertainty with regard to a continuation of the work.

Plant-Stimulants. I have, however, carried out a small series of experiments on the effect of plant-stimulants on indican production. The substances tested were the sulphates of copper, iron (ferrous), nickel, magnesium, and manganese.

Seed collected from a single Java indigo plant was sown in each of ten large earthenware pots, containing 36 lbs of uniform and fairly rich potting soil, in April. In four cases the plants failed. In the remaining six pots several healthy plants were established, and one plant was left in each. One pot was treated with each of the above mentioned salts in June, and the sixth was left untreated. The salts were applied in very dilute solutions (·04 per cent.) by means of funnels inserted in the soil; ·2 gram was applied in each case. It was not possible to duplicate the experiments, as should have been done, since only six pots were available; the results are, however, worth recording since they are somewhat remarkable and may serve as useful indications for future work.

In August the plants were all about 3 feet high, but the one treated with copper sulphate showed a markedly more vigorous growth than the rest. All were cut down to within 1½ inch of the surface of the soil, and the plants weighed and analysed. The following results were obtained :—

Treatment.	Weight of plant.	Leaf per cent.	Percentage of indigotin in leaf.	Total indigotin in plant.
	Grams.			Grams.
Copper sulphate ..	256	45·3	·607	·704
Ferrous ,, ..	157	45·2	·377	·274
Nickel ,, ..	125	42·4	·300	·159
Magnesium ,, ..	179	46·3	·420	·348
Manganese ,, ..	190	43 2	·290	·238
Blank.. ..	136	42·5	·322	·186

The most conspicuous point about these results is the enormous superiority of the plant treated with copper sulphate over the others,

both in respect of vigour of growth and indican-content of t e leaf. The total indigotin obtainable from this plant was nearly double that obtainable from the next best, the plant treated with magnesium sulphate.

In November the plants were cut a second time. Again the plant treated with copper sulphate showed the most vigorous growth, having more branches and a generally more bushy habit than the rest. The plants were cut back to the base of the new shoots and these were treated as before. The following were the results :—

Treatment.	Weight of plant.	Leaf per cent.	Percentage of indigotin in leaf.	Total indigotin in plant.
	Grams.			Grams.
Copper sulphate ..	80	52·5	·216	·090
Ferrous ,, ..	47	51·0	·311	·074
Nickel ,, ..	52	51·9	·274	·074
Magnesium ,, ..	38	55·2	·401	·084
Manganese ,, ..	71	52·1	..	..
Blank.. ..	38	50	·402	·076

Here again copper sulphate gives the best results, but, whereas at the first cutting it was due to high indican-content of the leaf as well as to vigour of growth, the colour-content is now the lowest (far lower than the blank), and the superiority is due solely to the larger plant produced. The plant treated with magnesium sulphate is again the second best, and is very much nearer the copper-treated plant than at the first cutting judged on the "total" results, whilst it is very much better on the leaf analysis. The analysis of the leaf of the plant treated with manganese was, unfortunately, lost.

Combining the results of the two cuttings and expressing them as the total indigotin obtainable from the plants we obtain the following figures :—

Treatment.	Total indigotin obtainable from the plant in two cuttings.
	Grams.
Copper sulphate	·794
Magnesium	·432
Ferrous	·348
Nickel	·233
Blank	·262

Thus in spite of its falling off at the second cutting the copper-treated plant has given by far the highest yield of indican. The plants which received magnesium and ferrous sulphates also show a marked increase over the blank.

These results are in many ways remarkable. In the first place it is significant that the copper salt, which had the most marked effect, was the most violent poison employed. The fact that the indican-content of the plant so treated was so much greater, in proportion to the other plants, at the first cutting than at the second looks as if it were directly connected with the action of the copper, which may be expected to have had a greater action during the period of growth immediately succeeding its application. It may also have induced the vigour of growth which characterised the plant throughout. In the second place it is remarkable to find any benefit arising from the application of magnesium sulphate, since this salt is by no means a violent poison and is a very common constituent of many Bihar soils. But it must be noted that these plants were not grown in ordinary field soil, but in specially prepared potting soil. This probably accounts for the generally low colour-content of the plants. Recollecting that the average colour-content of the leaf of the plant grown in the ordinary way is ·7—·8 per cent., it will be seen that the figures obtained in these experiments were abnormally low, in fact the highest obtained, that for the leaf of the copper-treated plant at its first cutting did not reach the average of the ordinary Java plant we were cutting at the time. I have frequently pointed out that plant growing on rich soil is characterised by the low indican-content of its leaf, and these experiments seem to afford further confirmation of the point. The inten-

tion in using this rich soil was in order to try to determine if the vigour of growth characteristic of indigo in rich soil could be maintained without the corresponding decrease in the colour-content of the leaf which accompanies it. This can hardly be said to have been realised in any case, though the copper salt showed the desired tendency. It seems, as far as it goes, as if copper leads to vigour of growth and an early development of a high indican-content (*i.e.*, what is commonly called " early ripening "), whilst magnesium leads to good leaf development and a moderately high, and steady, indican-content of the leaf.

An experiment has recently been started with copper sulphate on field soil on a plot divided into halves, one of which was irrigated with water containing this salt and the other with the same amount of plain water; but the plant is yet too young to form any opinion as to the result. It would be well worth trying heavier doses of copper on rich soils, and both magnesium and iron seem to merit further experiment. In fact work along these lines seems to justify considerable extension but, like that on the effect of ordinary manurial substances, it is no good starting this until some settlement with regard to the future of the work gives some promise of seeing it brought to a conclusion.

Biology.

It would be useless at this stage to seek an explanation of the effect of these small dose of poisons, indeed until they are confirmed they cannot be said to be more than the barest indications of possibilities. The fact is we know absolutely nothing about the biological aspect of the production of indican, and, until we do so, we cannot hope to find an explanation of the effect on it of changes in the plant's environment.

Bio-Chemistry.

If we knew why the plant forms indican at all it would help us enormously in determining the conditions which make for its maximum production; but we do not. Obviously the formation of indigotin has nothing to do with it, since this compound is never formed during the plant's life if it is allowed to run its normal course. Why then does it produce indican and along with it an enzyme whose special function seems to be to split it up into the component sugar and indigotin-yielding indoxyl? The theory which seems to carry most probability is that indoxyl is a nitrogenous waste product of the plant's metabolism which is combined with glucose and stored as indican until the nitrogen is required by the plant at the period of seed formation; the indican is then broken down by the action of the enzyme (which may also function in its formation), and the indoxyl goes to assist the formation of the nitrogenous products which are stored in the seed for the nourishment of the seedling plant. This theory seems to receive support from several observations. In the first place indoxyl is very

closely related chemically to indol. Indol is known to be a common nitrogenous waste product of the metabolism of some animals, so that it does not seem improbable that indoxyl should function in the same way in the metabolism of some plants (*i.e.*, those which yield indigotin). In the second place the indican-content of the leaf of those indigo-yielding plants which have been studied (*Indigofera arrecta* and *sumatrana*) is known to drop as soon as the seed sets and to gradually decrease as the seed forms, so that it seems probable that it is drawn upon to assist in the process of seed-formation. Thirdly, we have the observation that indigo plants growing under conditions of poor nourishment, or, apparently (judging by the experiments on the influence of poisons which have just been recorded), under other adverse conditions, tend to secrete abnormally large quantities of indican, more particularly at comparatively early stages of the plants' development, whilst those plants which are richly nourished do not do so; moreover there is invariably a tendency to earlier and more vigorous seeding in ill-fed plants. Now it may be taken as a rule of nature that a struggle for existence on the part of any living organism results in an increased effort to reproduce; in the case of a higher plant this effort finds expression in the formation of seed. If then indican is a necessary precursor of seed-development in indigo-yielding plants, it would seem to be in accordance with this rule that adverse conditions should tend to its increased development; and this is precisely what we find to be the case.

An extensive series of experiments on plants in pot-culture, such as I have suggested, should throw light on the value of this theory, and, if it is supported, help to show how the best conditions for attaining maximum indican production, without loss in the general vigour of the plant, may be attained. It will then be necessary to determine how nearly these conditions can be reproduced in practice. If the theory holds it would seem to follow that the plant which gives the best yield of seed under normal conditions should also be the best indican-producer; a point on which we have at present no evidence.

Heredity. Another aspect of the biological problem is that of heredity. Little though we know of the conditions of environment which determine the production of indican we know still less of the factors which influence the inheritance of the indican-producing faculty from parent plant to progeny. Extremely little is known of the laws which govern the inheritance of what may be termed chemical properties (in contradistinction to physical ones, such as the colour of flowers or length of stems) in any plants. The practical importance attaching to the problem has led to a certain amount of knowledge in the case referred

to in my last report, that of the sugar-beet, and a few others of a similar sort might perhaps be quoted. But in all these cases, so far as I am aware, the simple principle of deriving seed systematically from high-yielding parent plants is all that has been done, and no attempt has been made to apply the more modern knowledge of the laws of heredity to them. In the case of the indigo plant we are concerned with a different type of chemical compound to any of those which have been dealt with even in this way; nothing has been done, even in the way of simple selection, in the case of a plant which is cultivated solely for the production of a glucoside, and we do not even know if a faculty for the production of indican in large quantity is an inheritable characteristic at all. It may be that it is solely dependent on such conditions of environment as have been dealt with in the last paragraph, but the existence of species of *Indigofera* which have as constantly different indican-producing power under normal conditions as *Indigofera arrecta* and *sumatrana* seems opposed to this. Still less has anything been attempted in the way of tracing the results of scientifically-controlled breeding in such a case as that with which we have to deal in the indigo-plant.

The field here is an enormous one, calling for years of patient work from both a chemist and a biologist schooled in the most recent views on heredity, and I am convinced that it is only by such careful study of the production of indigo in its biological aspects that any further material advance is to be made by scientific aid.

Selection.

The start we have made on selection along the simple line referred to above, the systematic derivation of seed from selected high indigotin-yielding parent plants, is bound to be mere groping in the dark until we know more of the biological conditions which regulate these things. They may turn out a success from the practical point of view or they may not, but if they do so it will be largely a matter of good luck.

Java Plant.

All that has been done in the selection of the Java plant so far has been to sow plots of the seed gathered from the selected individual plants referred to in my last report. The sowing was delayed in anticipation of some decision being arrived at as to the continuation of the work, but, this not being forthcoming, it was carried out in November on the instructions of the Sirsiah Committee. Owing to the late ness of the season and the extremely short moisture it was necessary to irrigate an area of land for the purpose. The plants have suffered a good deal from the cold and from insect attacks in their early stages, but in most cases sufficient growth will probably be obtained to determine how far the faculty of high indican-production, as well as of

various morphological characteristics, is passed on through the seed. The seed sown was very uniform in the case of each individual parent plant, but showed most remarkable differences when the various samples were compared with one another, particularly after treatment with acid. The colours varied from almost white to deep brown, and the sizes and shapes from that of a poppy seed to that of Sumatrana indigo. This seems to support the view which I have always held, that there are many varieties of plant comprised under the term "Java indigo"; what their relative values are from the planter's point of view remains to be seen.

Some larger plots ($\frac{1}{15}$ acre) have also been sown with seed selected from exceptionally fine plants, and also from exceptionally early-seeding ones, on the Rajpore seed-farm last year, in order to see how far these characteristics are inherited and what value attaches to rough selection of this kind.

No new plants have been selected for seed-bearing this year. Such work, to be done to full advantage, must be carried out in collaboration with a botanist, but the samples which have been sown this year should be sufficient to throw light on the general question of the inheritance of a high indican-yielding-faculty.

There seem to be a number of morphological differences observable at the seeding stage of the plant in any field, but it is extremely difficult for any but a trained field botanist to form an opinion as to which are true varietal characteristics. I propose, however, selecting seed from a few of the more obviously distinguishable plants on the seed plots this year so that they may be grown separately if opportunity occurs. It should be possible to determine in this way at least if they breed true morphologically, though it by no means follows that, if they do so, they will also breed true with regard to indican production.

Sumatrana Plant.

No further progress has been made in the selection of Sumatrana indigo except that the stock of seed of the various sub-varieties has been increased. These were all sown on irrigation in April, and samples of the various types of plant analysed in September. The results of the analyses are hardly worth recording. They do not confirm those recorded in my 1906-07 report, but put the plants in an entirely different order of value. This may be partly due to the later season at which the lyses were carried out, but it is probably also partly due to cross-breeding amongst the plants. They have now been grown side by side for several seasons without any specia precautions being taken to prevent cross-fertilisation. If this has taken place the identity of the various types will probably be destroyed and they will

have to be collected afresh if further work is to be done on these lines. This is, however, another point on which the collaboration of a botanist is essential. A quantity of seed was collected from each sub-variety in November and has been stored for future use.

"Nitro-Bacterine.

A new preparation for the inoculation of leguminous plants has been brought out during the past year by Prof. Bottomley, of King's College, London, under the name "Nitro-Bacterine." Prof. Bottomley has prepared a special culture for indigo which is being tried at Sirsiah and by several planters. The principle on which it depends is precisely the same as that underlying the United States preparation referred to in my 1906-07 report, but Prof. Bottomley is said to have devised a new method of cultivating and preserving the nodule organisms by which the cultures are rendered more efficacious. It is too early yet to be able to record any results.

The Java Plant.

The Java plant has been the salvation of the indigo industry this year. It is now established over about half of the total cultivation of Bihar, but, since a very large proportion of the Sumatrana sowings failed owing to the very short moisture, it has been responsible for a very much larger share of this year's production than half of the cultivation would imply. For this reason a comparison of the relative yields of indigo from each type of plant is more than usually useless this year. If expressed on the areas sown it would be ridiculously in favour of the Java plant; and, if expressed only on the areas in which a crop was obtained, it means making a comparison between the production of a very large area of Java plant on lands of all qualities and that of a comparatively small area of Sumatrana plant on picked lands which succeeded in holding their moisture. The only basis on which a comparison of any value can be made is that of the relative yields per 100 maunds of plant, but even this is likely to be deceptive, not only because the Sumatrana plant is drawn only from those good moisture-holding lands on which it survives and the Java plant from all manner of lands, but also because the former, owing to its comparatively shallow root-system, is likely to be affected more by the drought, and to react by an abnormal production of indican, than the latter with its much deeper root-system. The result of a comparison on this basis in a year like the past is probably, therefore, unduly in favour of the Sumatrana plant. So far as they go, however, the figures are almost precisely the same as those obtained last year—15 seers, 10 chittacks per 100 maunds for the Java plant, and 11 seers, 14 chittacks for the Sumatrana; but it must be borne in mind that, in the first place, only 25 concerns sent returns in to the Association, and out of these only 14 give separate figures for the Sumatrana plant, the

rest either had no Sumatrana or manufactured what they had together with their Java plant; so that the figures do not represent very true averages. On the whole I do not think these returns are worth collecting. No doubt exists as to the superior value of the Java plant in most circumstances, and most planters are now able to estimate the average relative values of the two kinds of plant over a few years on their own concerns; but too much variation exists between different concerns and different seasons for average returns for the whole of Bihar, however obtained, to have much value.

Our own returns show an average of 14 seers, 11 chittacks per 100 maunds of Java plant, and as much as 12 seers, 6 chittacks per 100 maunds of Sumatrana; but these figures again are quite misleading, since our Java crop was a moderately large one, containing all kinds of plant from all kinds of lands, whilst our Sumatrana crop consisted of only 500 maunds in all, and this was small leafy plant derived from small patches of cultivation where it managed to survive the drought.

The outturn during the coming season will depend even more on Java indigo than it did during the past one; in fact the cultivation of Sumatrana plant will probably be very small indeed over the greater part of Bihar, so short has the rainfall been during the past year. It is in the highest degree unfortunate that there has been an unbroken succession of abnormal seasons ever since the Java plant was taken up in Bihar at all widely, for there is no doubt that the possibilities it involves are not yet fully grasped either by planters or by their synthetic competitors, and every year lost means advantage to the latter.

Quality.

The average quality of the indigo produced at Sirsiah from Java plant was 61·9 per cent., and from Sumatrana 68·2 per cent.; the latter is, however, of little value as an average owing to the very small amount of plant it represents. There was a marked difference between the quality of the "moorhun" and "khoontie" produce from the Java plant, the former averaging 65·8 per cent. and the latter only 58·2; no doubt this is connected with the very short rainfall and consequent stunted condition of the "khoontie" plant. On the whole the average quality on analysis is much the same as last year, but, judged by appearance, this year's crop is distinctly inferior; the cakes are very brittle; and many of them broken. This is, I believe, true of a great deal of the indigo which has been produced in Bihar this year, and may, I think, be also attributed to the season. The abnormal atmospheric conditions no doubt led to too rapid drying which induced cracking and breaking of the cakes. It might probably

be avoided by hanging moist sheets in the cake house and keeping it shut up as much as possible. I would recommend this being tried whenever the season is abnormally dry.

Java seed production.

The crop from the 1906 sowings on the seed-farms was distributed during 1908. The combined outturn was very small, partly owing to the drought in 1907 and partly to the total failure of the crop on the Dowlutpore farm resulting from the attack of a fungoid disease; the price of the seed produced had therefore to be made proportionately high in order to cover expenses. After this experience, coupled with the similar one of the previous year, it was decided that some reformation was necessary in the seed-farm scheme, since it was obviously unsound to rely on as few as three farms for the seed-supply of Bihar. Accordingly the seed-farms have been done away with, and, as an alternative, it has been decided that in future every planter shall establish a farm of his own on which he will grow seed under the most approved conditions and exchange the produce with another planter. In order to provide a stock of the best possible seed for these farms planters have been asked to select the very best plants from the whole of their cultivation annually, to reserve these for seed purposes, and to send a small consignment of this picked seed to the Association. The best of these consignments will then be selected, and the selected consignments bulked and reissued to planters for seed-farm purposes annually.

This scheme should safeguard all the necessary interests. Sowing the seed-farms with seed derived from selected plants grown all over Bihar will ensure constant renewal of the stock and its establishment from the very best sources available. The exchange of the produce of the various farms annually is, of course, left in the hands of planters themselves, but it is felt that the necessity for this is now fully realised and that cultivation of the farms under optimum conditions can now be relied upon. In this case the scheme should afford all that is required and minimise the risk of shortage of seed in any particular year very considerably.

In July last I issued a note setting out the points on which I considered the selection of the plants for seed-bearing purposes on the various concerns should be based, and, I believe, many planters have made their selection this year as far as possible on the lines proposed. It was impossible to be very definite in this because we have yet so little knowledge on the point, and it is doubtful whether planters will ever be able to select to the best advantage, since so much may turn upon chemical analysis. Any information which is forthcoming on this, and on the general question of methods of seed cultivation, will

be made known to planters as soon as possible so that immediate advantage of it may be taken.

The second year's crop of seed was gathered from the seed plots, mentioned in my last report, early last year. The results are interesting as showing the relative yields of seed which may be expected from plant in its first year and its second, but it must be remembered that the rainfall in 1907 was very much less than that in 1906, which probably had something to do with the difference in the results. The figures of the first crop are repeated alongside those of the second in the following table for the purpose of comparison :—

Treatment.	First year.			Second year.	
	M.	S.	Ch.	S.	Ch.
Unthinned and uncut ..	1	4	12	20	5
Do. do. and "topped"	1	22	9	23	3½
Plants 2′ apart		39	8	16	5½
,, 4′ ,, ...		20	13	11	7¼
,, 6′ ,, ...		17	9	9	11½

Thus only about half the yield was obtained in the second year in each case. The unthinned, uncut and "topped" plots still give the best yield though their crop has fallen off more than that of any of the others.

The new experiments started at the end of 1906 gave their first crops at the same time ; the following were the results :—

Treatment.	Yield.	
	S.	Ch.
Unthinned and uncut	25	12¾
Do. do. and "topped" ..	23	7½
1′ apart and "topped"	29	2¼
2′ ,, ,, ,, ...	20	12½
8′ strips and 6′ intervals	18	13½
8′ ,, ,, 3′ ,, ...	24	10

The general low returns here, as compared with those of the first year of the former series, suggests that the difference in yield from the latter at the first and second cropping was more a matter of climatic conditions than of age. The results show that thinning out to 1′ apart and then "topping" has given the best results, and, in the case of the unthinned plant, topping does not appear to have been of advantage. This is probably due to the fact that the plant on the unthinned plots in this series of experiments was very close, very much closer than on the corresponding plots in the 1905 series, so that "topping" has not had the same opportunity to lead to branching and consequent increased yield of seed as in the latter case. The fact that it has been of advantage where the plants were thinned out to 1′ apart seems to confirm this explanation. The result of growing the plant in 8′ strips with 3′ intervals of fallow between them seems to be distinctly good, but no better than that of growing a moderately thin crop and "topping" it. I think this latter method is most to be recommended, from the point of view of yield, for employment on planters' seed-farms.

As regards the quality of the seed grown under the various conditions I have not yet any results. The seed derived at the first cropping from the 1905 plots and sown in 1907 by Mr. Turnbull failed, whilst the seed obtained from their second cropping, and from the first cropping of the 1906 series, has only just been sown.

Conclusion.

I have again to thank the members of the Sirsiah staff for the excellent work they have done during the year, and many planters for information and assistance which has been very kindly given.

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